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This handbook for the port of Marseille, one in a series of severe weather guides for Mediterranean ports, provides decision-making guidance for ship captains whose vessels are threatened by actual or forecast strong winds, high seas, restricted visibility or thunderstorms in the port vicinity. Causes and effects of such hazardous conditions are discussed. Precautionary or evasive actions are suggested for various vessel situations. The handbook is organized in four sections for ready reference: general guidance on handbook content and use; a quick-look captain's summary; a more detailed review of general information on environmental conditions; and an appendix that provides oceanographic information.

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SEVERE WEATHER GUIDE MEDITERRANEAN PORTS

7. MARSEILLE

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED

CONTENTS

FOREWORD

This handbook on Mediterranean Ports was developed as part of an ongoing effort at the Naval Environmental Prediction Research Facility to create products for direct application to Fleet operations. The research was conducted in response to Commander Naval Oceanography Command (CNOC) requirements validated by the Chief of Naval Operations (CNO).

As mentioned in the preface, the Mediterranean region is unique in that several areas exist where local winds can cause dangerous operating conditions. This handbook will provide the ship's captain with assistance in making decisions regarding the disposition of his ship when heavy winds and seas are encountered or forecast at various port locations.

Readers are urged to submit comments, suggestions for changes, deletions and/or additions to NOCC, Rota with a copy to the oceanographer, COMSIXTHFLT. They will then be passed on to the Naval Environmental Prediction Research Facility for review and incorporation as appropriate. This document will be a dynamic one, changing and improving as more and better information is obtained.

M. G. SALINAS
Commander, U.S. Navy

PORT INDEX

The following is a tentative prioritized list of Mediterranean Ports to be evaluated during the five-year period 1988-92, with ports grouped by expected year of the port study's publication. This list is subject to change as dictated by circumstances and periodic review.

1988 NO.	PORT
1	GAETA, ITALY
2	NAPLES, ITALY
3	CATANIA, ITALY
4	AUGUSTA BAY, ITALY
5	CAGLIARI, ITALY
6	LA MADDALENA, ITALY
7	MARSEILLE, FRANCE
8	TOULON, FRANCE
9	VILLEFRANCHE, FRANCE
10	MALAGA, SPAIN
11	NICE, FRANCE
12	CANNES, FRANCE
13	MONACO
14	ASHDOD, ISRAEL
15	HAIFA, ISRAEL
	BARCELONA, SPAIN
	PALMA, SPAIN
	IBIZA, SPAIN
	POLLENSA BAY, SPAIN
	VALENCIA, SPAIN
	CARTAGENA, SPAIN
	GENOA, ITALY
	LIVORNO, ITALY
	SAN REMO, ITALY
	LA SPEZIA, ITALY
	VENICE, ITALY
	TRIESTE, ITALY

1989	PORT
	SPLIT, YUGOSLAVIA
	DUBROVNIK, YUGOSLAVIA
	TARANTO, ITALY
	PALERMO, ITALY
	MESSINA, ITALY
	TAORMINA, ITALY
	PORTO TORRES, ITALY

1990	PORT
	BENIDORM, SPAIN
	ROTA, SPAIN
	TANGIER, MOROCCO
	PORT SAID, EGYPT
	ALEXANDRIA, EGYPT
	ALGIERS, ALGERIA
	TUNIS, TUNISIA
	GULF HAMMAMET, TUNISIA
	GULF OF GABES, TUNISIA
	SOUDA BAY, CRETE

1991	PORT
	PIRAEUS, GREECE
	KALAMATA, GREECE
	THESSALONIKI, GREECE
	CORFU, GREECE
	KITHIRA, GREECE
	VALETTA, MALTA
	LARNACA, CYPRUS

1992	PORT
	ANTALYA, TURKEY
	ISKENDERUN, TURKEY
	IZMIR, TURKEY
	ISTANBUL, TURKEY
	GOLCUK, TURKEY
	GULF OF SOLLUM

PREFACE

Environmental phenomena such as strong winds, high waves, restrictions to visibility and thunderstorms can be hazardous to critical Fleet operations. The cause and effect of several of these phenomena are unique to the Mediterranean region and some prior knowledge of their characteristics would be helpful to ship's captains. The intent of this publication is to provide guidance to the captains for assistance in decision making.

The Mediterranean Sea region is an area where complicated topographical features influence weather patterns. Katabatic winds will flow through restricted mountain gaps or valleys and, as a result of the venturi effect, strengthen to storm intensity in a short period of time. As these winds exit and flow over port regions and coastal areas, anchored ships with large 'sail areas' may be blown aground. Also, hazardous sea state conditions are created, posing a danger for small boats ferrying personnel to and from port. At the same time, adjacent areas may be relatively calm. A glance at current weather charts may not always reveal the causes for these local effects which vary drastically from point to point.

Because of the irregular coast line and numerous islands in the Mediterranean, swell can be refracted around such barriers and come from directions which vary greatly with the wind. Anchored ships may experience winds and seas from one direction and swell from a different direction. These conditions can be extremely hazardous for tendered vessels. Moderate to heavy swell may also propagate outward in advance of a storm resulting in uncomfortable and sometimes dangerous conditions, especially during tending, refueling and boating operations.

This handbook addresses the various weather conditions, their local cause and effect and suggests some evasive action to be taken if necessary. Most of the major ports in the Mediterranean will be covered in the handbook. A priority list, established by the Sixth Fleet, exists for the port studies conducted and this list will be followed as closely as possible in terms of scheduling publications.

RECORD OF CHANGES

CHANGE NUMBER	DATE OF CHANGE	DATE ENTERED	PAGE NUMBER	ENTERED BY

1. GENERAL GUIDANCE

1.1 DESIGN

This handbook is designed to provide ship captains with a ready reference on hazardous weather and wave conditions in selected Mediterranean harbors. Section 2, the captain's summary, is an abbreviated version of section 3, the general information section intended for staff planners and meteorologists. Once section 3 has been read, it is not necessary to read section 2.

1.1.1 Objectives

The basic objective is to provide ship captains with a concise reference of hazards to ship activities that are caused by environmental conditions in various Mediterranean harbors, and to offer suggestions for precautionary and/or evasive actions. A secondary objective is to provide adequate background information on such hazards so that operational forecasters, or other interested parties, can quickly gain the local knowledge that is necessary to ensure high quality forecasts.

1.1.2 Approach

Information on harbor conditions and hazards was accumulated in the following manner:

A. A literature search for reference material was performed.

B. Cruise reports were reviewed.

C. Navy personnel with current or previous area experience were interviewed.

D. A preliminary report was developed which included questions on various local conditions in specific harbors.

E. Port/harbor visits were made by NEPRF personnel; considerable information was obtained through interviews with local pilots, tug masters, etc; and local reference material was obtained (See section 3 references).

F. The cumulative information was reviewed, combined, and condensed for harbor studies.

1.1.3 Organization

The Handbook contains two sections for each harbor. The first section summarizes harbor conditions and is intended for use as a quick reference by ship captains, navigators, inport/at sea OOD's, and other interested personnel. This section contains:

A. a brief narrative summary of environmental hazards,

B. a table display of vessel location/situation, potential environmental hazard, effect-precautionary/evasion actions, and advance indicators of potential environmental hazards,

C. local wind wave conditions, and

D. tables depicting the wave conditions resulting from propagation of deep water swell into the harbor.

The swell propagation information includes percent occurrence, average duration, and the period of maximum wave energy within height ranges of greater than 3.3 feet and greater than 6.6 feet. The details on the generation of sea and swell information are provided in Appendix A.

The second section contains additional details and background information on seasonal hazardous conditions. This section is directed to personnel who have a need for additional insights on environmental hazards and related weather events.

1.2. CONTENTS OF SPECIFIC HARBOR STUDIES

This handbook specifically addresses potential wind and wave related hazards to ships operating in various Mediterranean ports utilized by the U.S. Navy. It does not contain general purpose climatology and/or comprehensive forecast rules for weather conditions of a more benign nature.

The contents are intended for use in both pre-visit planning and in situ problem solving by either mariners or environmentalists. Potential hazards related to both weather and waves are addressed. The oceanographic information includes some rather unique information relating to deep water swell propagating into harbor shallow water areas.

Emphasis is placed on the hazards related to wind, wind waves, and the propagation of deep water swell into the harbor areas. Various vessel locations/situations are considered, including moored, nesting, anchored, arriving/departing, and small boat operations. The potential problems and suggested pre-cautionary/evasive actions for various combinations of environmental threats and vessel location/situation are provided. Local indicators of environmental hazards and possible evasion techniques are summarized for various scenarios.

CAUTIONARY NOTE: In September 1985 Hurricane Gloria raked the Norfolk, VA area while several US Navy ships were anchored on the muddy bottom of Chesapeake Bay. One important fact was revealed during this incident: Most all ships frigate size and larger dragged anchor, some more than others, in winds of over 50 knots. As winds and waves increased, ships 'fell into' the wave troughs, BROADSIDE TO THE WIND and become difficult or impossible to control.

This was a rare instance in which several ships of recent design were exposed to the same storm and much effort was put into the documentation of lessons learned. Chief among these was the suggestion to evade at sea rather than remain anchored at port whenever winds of such intensity were forecast.

2. CAPTAIN'S SUMMARY

The Port of Marseille is located at 43°20'N 05°20'E on the southern coast of France (Figure 2-1).

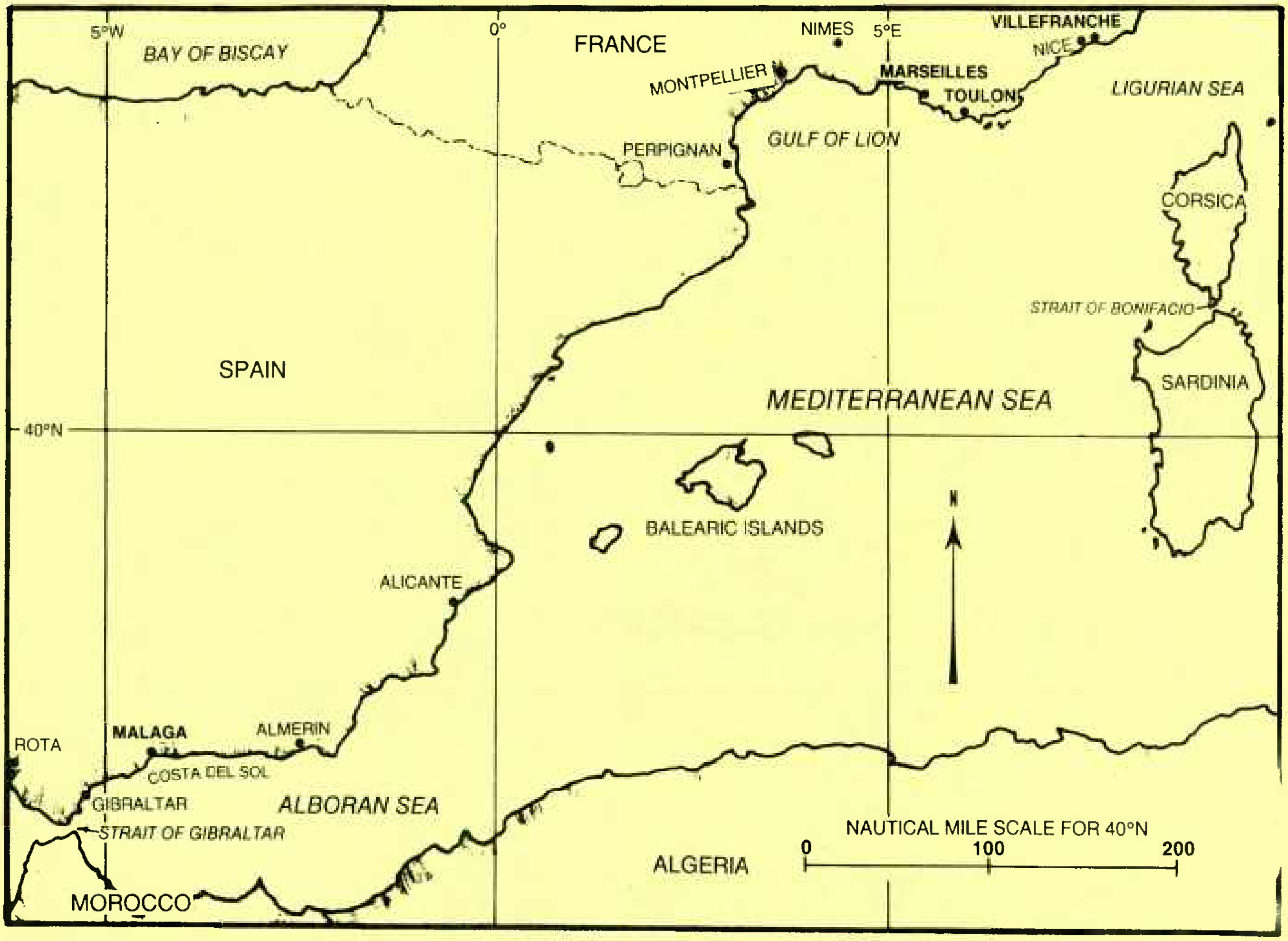

Figure 2-1. Western Mediterranean Sea.

The Port of Marseille is well protected from waves from the open ocean, but is exposed to winds. The orientation of the Port (Figure 2-2) minimizes the impact of the strongest wind--the northwesterly Mistral--to the extent that normal port operations in the inner harbor are carried out with little disruption. Winds from other directions do affect port operations.

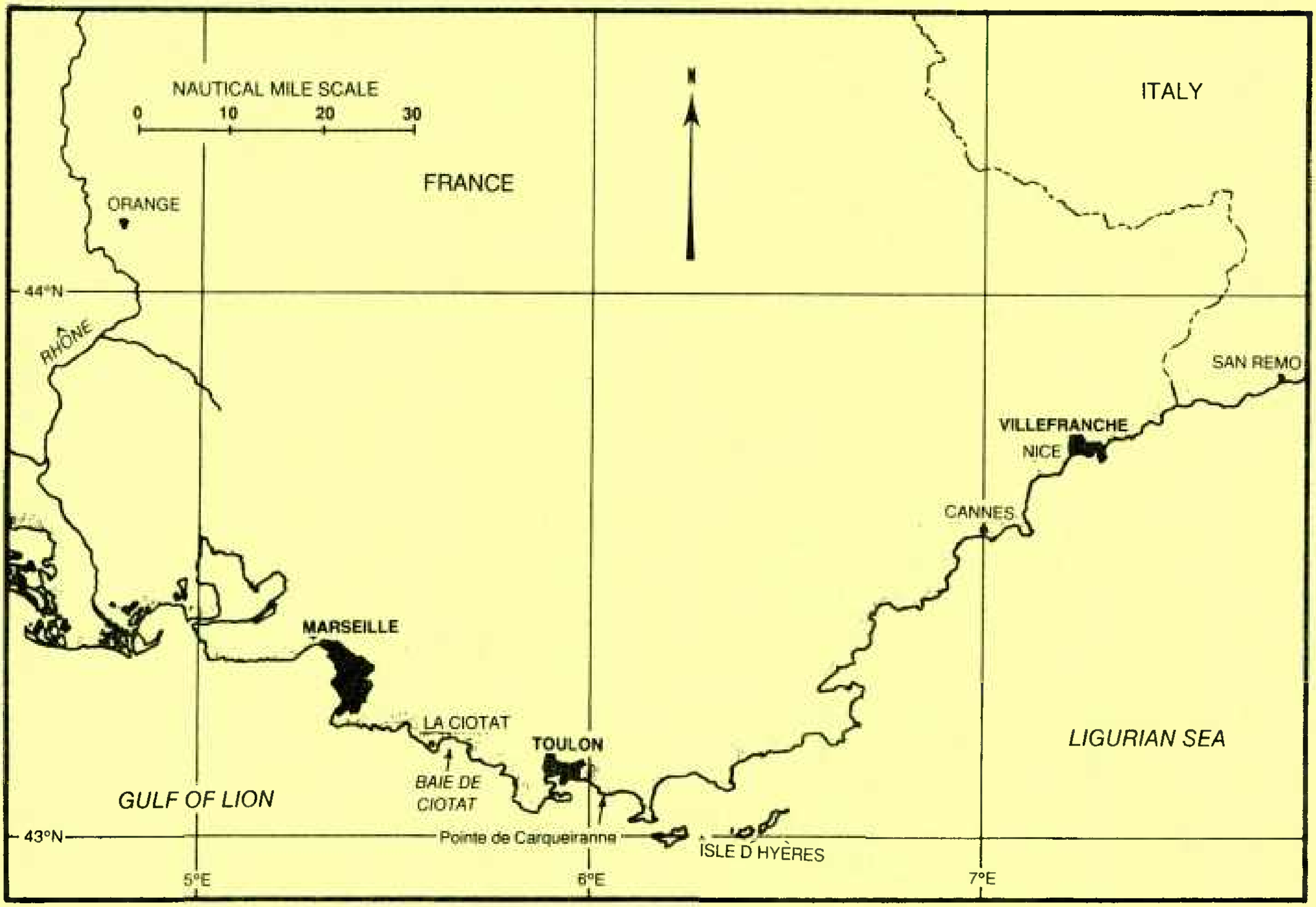

Figure 2-2. Ports of Marseille, Toulon, Villefranche.

The Port is bordered on the northeast side by the French landmass (Figure 2-3). The southwest side of the elongated facility is bordered for most of its length by a long, 30 ft (9.1 m) high breakwater. U.S. Naval vessels normally utilize Avant Port Nord, the northern part of the Port, which is comprised of the following basins: Bassin Mirabeau, where the carrier berth is located, Bassin Leon Gourret (Darse Sud), Bassin du Président Wilson, Bassin de la Pinède, Bassin National, and Bassin de la Gare Maritime.

The anchorage is located outside the breakwater adjacent to Mole Leon Gourret, and is exposed to wind from all directions and waves from the southwest quadrant. According to Hydrographer of the Navy (1965), anchorage in Rade de Marseille "is not recommended as it does not afford safe protection from easterly winds in winter or from the sudden changes of wind."

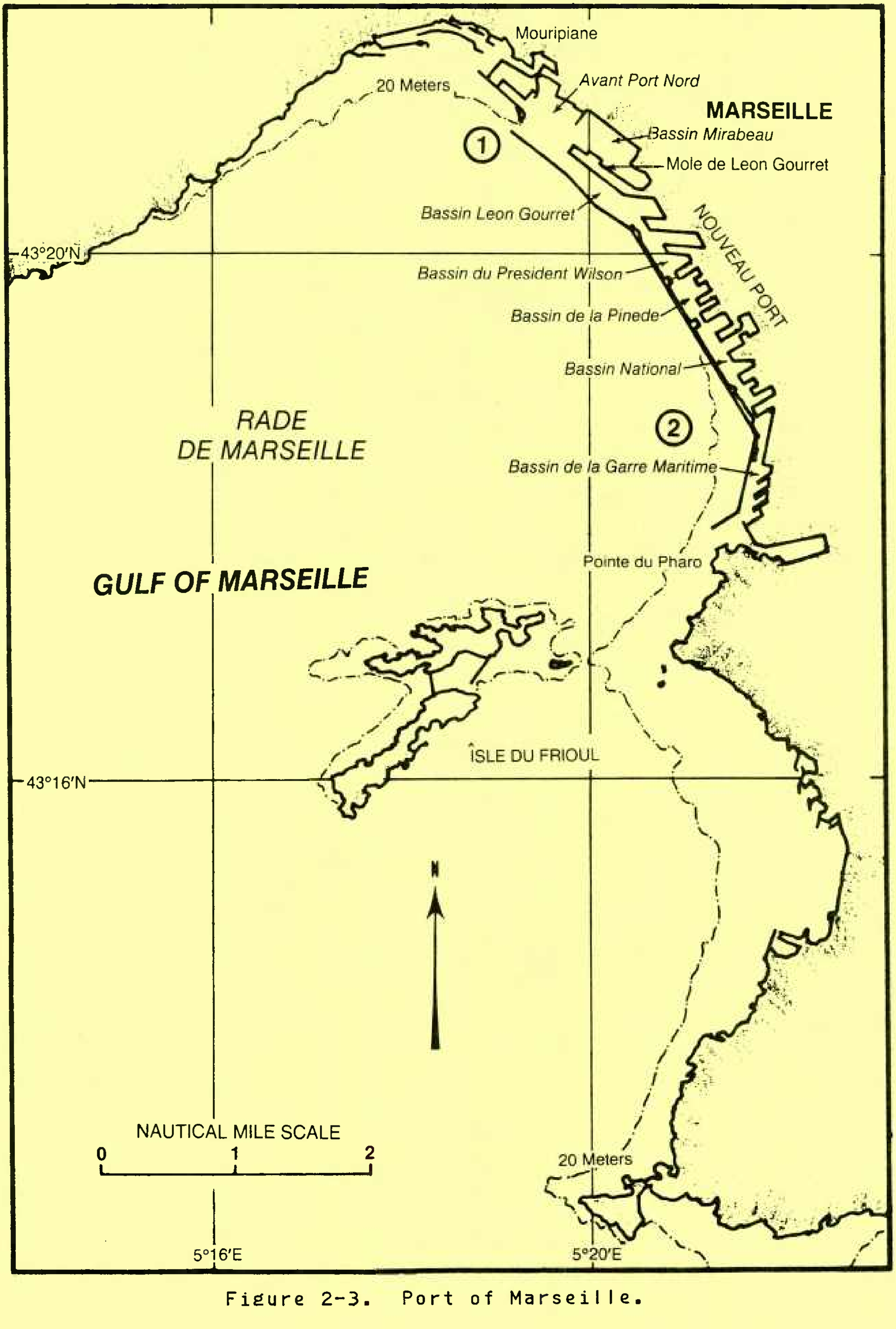

Figure 2-3. Port of Marseille.

Tides at the Port of Marseille are insignificant, with a change of about 1 ft (30 cm) normal. Hydrographer of the Navy (1965), also warns of "sudden changes in the sea level of as much as 8 inches...sometimes occur, and at the same time, currents of short duration may be experienced in the harbor entrances; this generally occurs during strong onshore winds with a high sea." In general, currents are negligible, being irregular and not set in a constant direction in any season. However, a wind driven current will often precede the arrival of the wind.

Specific hazardous conditions, vessel situations and suggested precautionary/evasion action scenarios are summarized in Table 2-1. Hazards for both inport and at anchorage are addressed.

Table 2-1. Summary of hazardous environmental conditions for the Port of Marseille, France.

HAZARDOUS CONDITION	INDICATORS OF POTENTIAL HAZARD	VESSEL LOCATION/ SITUATION AFFECTED	EFFECT - PRECAUTIONARY/EVASIVE ACTIONS
1. Mistral wind - Strong NW'ly wind. * Strongest in afternoon, weakest just after midnight. * Occurs all year, but most common and strongest in late winter/early spring, weakest in summer. * On average, Mistral blows on 110 days per year at Marseille.	Advance warning. * Mistral will start when the following pressure differences are achieved-- highest pressure to west: * Perpignan - Marignane (Marseille), 3 mb. * Marignane (Marseille) - Nice, 3 mb. * Perpignan - Nice, 6 mb. * Wave clouds over mountains is an indicator of Mistral winds. * Mistral onset at Lus La Croix Haute provides a 2-3 hr advance warning of onset at Marseille, (3-hourly reports available). * NW'ly winds 25 kt at Orange indicates Mistral at Marseille in 3-4 hr. (Hourly reports available) * Mistral is indicated within 6 hr when normal ESE afternoon seabreeze at Perpignan shifts N'ly 25-30 kt and temperature drops at least 3°F. Duration. * Commonly lasts 3-6 days but may last 12 days without any important lulls. * When clouds come from E the Mistral will stop and E winds will start. * When strong winds and fractocumulus clouds come from N instead of NW, the Mistral will stop within 2 hr. Extent. * E of Iles d'Hyères there is a rapid decrease in the frequency and strength of Mistral. * When a 10 mb pressure difference exists between Toulon and Nice, the Mistral will spread E; with only 2 mb the Mistral will cease near Toulon. * Winds may extend far to sea; to Corsica and Sardinia and beyond. A local Mistral (vice widespread Mistral) may only extend 5-10 n mi to sea. Intensity. * Force 5 (17-21 kt) frequent, force 8 (34-40 kt) common, force 11 (56-63 kt) occasionally reached. * Gale force (force 8, 34-40 kt) occurs about 10-15 days per year during late winter and early spring. Associated weather. * Cold front which introduces Mistral brings rain and sometimes violent squalls. * After initial frontal weather the Mistral is usually accompanied by clear skies. * Areas in lee of high bluffs (Baie de Ciotat for example) are liable to violent squalls.	(1) Moored.	PORT ORIENTATION MINIMIZES MISTRAL WIND THREAT. INNER HARBOR IS CONSIDERED SAFE DURING MISTRAL. (a) Direction of wind is parallel to orientation of most quays, but wind has slight tendency to force vessels off moorings. * Normal mooring procedures are adequate for safety. (b) Be aware for wind chill factor. * Minimize personnel exposure on weather decks during cold temperatures.
		(2) Anchored.	MEDITERRANEAN PILOT ADVISES THAT ANCHORAGE IN RADE DE MARSEILLE IS NOT RECOMMENDED AS IT DOES NOT AFFORD SAFE PROTECTION FROM SUDDEN CHANGES OF WIND. (a) Wind force may cause vessels to drag anchor toward shallow water/breakwater SE of anchorage. * Moving NW in Rade de Marseille may reduce effect. CAUTION: Be alert for shallow water. * Moving to more protected location E of Iles d'Hyères may be required. (b) Be aware of wind chill factor. * Minimize personnel exposure on weather decks during cold weather.
		(3) Arriving/departing.	(a) Orientation of entrance to Avant Port Nord and quays minimize problems during entrance/exit from port and berthing/deberthing operations. * Extra care must be exercised in inner harbor due to slow SOA and maneuvering problems caused by wind forces. * Early morning arrival/departure will normally result in less wind than will an afternoon evolution. Be aware of wind chill factor. * Minimize personnel exposure on weather decks during cold weather.
		(4) Small boats.	(a) Boating may be restricted to protected waters inside breakwater.

Table 2-1. (Continued)

HAZARDOUS CONDITION	INDICATORS OF POTENTIAL HAZARD	VESSEL LOCATION/ SITUATION AFFECTED	EFFECT - PRECAUTIONARY/EVASIVE ACTIONS
2. SW'ly winds/waves - May be called Marin, Aygalas or Marinada. * Not as strong as Mistral, but 30-40 kt not unusual. * Winds can raise heavy sea and swell in Rade de Marseille. * Wind direction is perpendicular to orientation of most quays.	Advance warning. * Most likely to occur in southerly flow preceding low pressure/frontal system approaching Marseille from W. Duration. * Once blowing, will likely continue until low pressure/frontal system passes area.	(1) Moored.	(a) Wind direction is perpendicular to quay orientation. * Moored vessels will be forced on/off berths. Doubling of mooring lines, may be required to keep position secure.
		(2) Anchored.	MEDITERRANEAN PILOT ADVISES THAT ANCHORAGE IN RADE DE MARSEILLE IS NOT RECOMMENDED AS IT DOES NOT AFFORD SAFE PROTECTION FROM SUDDEN CHANGES OF WIND. (a) Vessels may drag anchor toward shallow water/breakwater NE of anchorage. * Two anchors may provide adequate holding. * Weighing anchor and going to sea or moving to more protected waters east of Iles d'Hyères may be required until winds and waves subside.
		(3) Arriving/departing.	(a) Entrance/exit to/from Avant Port Nord may be difficult because of wind direction perpendicular to orientation of Port entrance and quays.
		(4) Small boats.	(a) Boating may be restricted to protected waters inside breakwater.
3. Lombarde wind - Cold E'ly wind originating in high Alps. * Winter/early spring phenomenon.	Advance warning. * Most likely to occur with a cold high pressure cell over France and central Europe, or high pressure SE of Europe and low pressure to the NW. * Watch for reports of wind/squalls/snow in mountains NE and E of Marseille. Duration. * Will persist until high cell weakens or is displaced.	(1) Anchored.	MEDITERRANEAN PILOT ADVISES THAT ANCHORAGE IN RADE DE MARSEILLE IS NOT RECOMMENDED AS IT DOES NOT AFFORD SAFE PROTECTION FROM EASTERLY WINDS IN WINTER OR FROM SUDDEN CHANGES OF WIND. (a) Strong event may cause vessels to drag anchor. * Two anchors may be adequate to forestall dragging, or; * Moving to more protected waters may be required. (b) Be aware of wind chill factor. * Minimize personnel exposure on weather decks.

For estimating shallow water wave heights, two points have been selected (Figure 2-3). Point 1 is near the northern entrance (Avant-Port Nord) to the inner harbor. Point 2 is in the anchorage area west of Bassin de la Garre Maritime (near the southern entrance to the inner harbor).

Table 2-2 provides the height ratio and direction of shallow water waves to expect at Points 1 and 2 when the deep water wave conditions are known.

The Marseille Point 1 conditions are found by entering Table 2-2 with the forecast or known deep water wave direction and period. The height is determined by multiplying the deep water height (8 ft) by the ratio of shallow to deep height (.8).

Example: Use of Table 2-2 for Marseille Point 1.

Deep water wave forecast as provided by a forecast center or a reported/observed deep water wave condition:

8 feet, 14 seconds, from 210°.

The expected wave condition at Marseille Point 1, as determined from Table 2-2:

6-7 feet, 14 seconds, from 215°.

NOTE: Wave periods are a conservative property and remain constant when waves move from deep to shallow water, but speed, height, and steepness change.

Table 2-2. Shallow water wave directions and relative height conditions versus deep water period and direction (see Figure 2-3 for location of the points).

FORMAT: Shallow Water Direction
Wave Height Ratio: (Shallow Water/Deep Water)

MARSEILLE POINT 1: (Near North Harbor Entrance) 120 ft depth

Period (sec)	6	8	10	12	14	16
Deep Water Direction	Shallow Water Direction and Height Ratio					
150°	185°	190°	200°	210°	215°	215°
	.4	.4	.3	.3	.3	.3
180°	190°	190°	205°	205°	205°	205°
	.5	.3	.1	.3	.4	.4
210°	210°	210°	210°	215°	215°	205°
	1.0	.9	.6	.6	.8	.5
240°	240°	240°	240°	240°	230°	235°
	1.0	.7	.5	.4	.4	.7
270°	260°	250°	245°	245°	240°	240°
	.6	.5	.4	.3	.3	.3

MARSEILLE POINT 2: (Fleet Anchorage) 96 ft depth

Period (sec)	6	8	10	12	14	16
Deep Water Direction	Shallow Water Direction and Height Ratio					
180°	190°	200°	200°	215°	225°	240°
	.3	.3	.3	.2	.2	.2
210°	185°	200°	200°	200°	215°	235°
	.4	.3	.3	.2	.2	.2
240°	240°	250°	250°	255°	260°	260°
	.3	.3	.2	.2	.1	.1
270°	265°	265°	260°	260°	260°	265°
	.5	.4	.3	.3	.2	.2

The local wind generated wave conditions for the anchorage area identified as points 1 and 2 are given in Table 2-3. All heights refer to the significant wave height (average of the highest 1/3 waves). Enter the local wind speed and direction in this table to obtain the minimum duration in hours required to develop the indicated fetch limited sea height and period. The time to reach fetch limited height is based on an initial flat ocean. When starting from a pre-existing wave height, the time to fetch limited height will be shorter.

Table 2-3. Gulf of Marseille. Local wind waves for fetch limited conditions at points 1 and 2 (based on JONSWAP model).

Point 1.

Format: height (feet)/period (seconds)
time (hours) to reach fetch limited height

Direction and\ Fetch \ Length \ (n mi)	Local Wind Speed (kt) 18	24	30	36	42
S 3 n mi	<2 ft	< 2ft	2/3 1	2/3 1	2-3/3 1
SW 120 n mi	5/7 7	8/8 8-9	8/9 8	10/9-10 7-8	9/10 7

Point 2

Direction and\ Fetch \ Length \ (n mi)	Local Wind Speed (kt) 18	24	30	36	42
WNW 5 n mi	<2 ft	2/3-4 1	2-3/3-4 1	3/3-4 1-2	3-4/3-4 1
W 80 n mi	3/7 7	4/7-8 7	4/8 6-7	4/8-9 6	5/9 5-6

Example:
To the west (270°) of Point 2 there is about a 80 n mi fetch (Figure 2-1). Given a west wind at 24 kt, the sea will have reached 4 feet with a period of 7-8 seconds within 7 hours. Wind waves will not grow beyond this condition unless the wind speed increases or the direction changes to one over a longer fetch length. If the wind waves are superimposed on deep water swell, the combined height may change in response to changing swell conditions. Wind wave directions are assumed to be the same as the wind direction.

Climatological factors of shallow water waves, as described by percent occurrence, average duration, and period of maximum energy (period at which the most energy is focused for a given height), are given in Table 2-4. See Appendix A for discussion of wave spectrum and energy distribution. These data are provided by season for two ranges of heights: greater than 3.3 ft (1 m) and greater than 6.6 ft (2 m).

Table 2-4. Shallow water climatology as determined from deep water wave propagation. Percent occurrence, average duration or persistence, and wave period of maximum energy for wave height ranges of greater than 3.3 ft (1 m) and greater than 6.6 ft (2 m) by climatological season.

MARSEILLE POINT 1:	WINTER	SPRING	SUMMER	AUTUMN
>3.3 ft (1 m)	NOV-APR	MAY	JUN-SEP	OCT
Occurrence (%)	11	5	5	8
Average Duration (hr)	10	9	10	16
Period Max Energy (sec)	9	9	9	9
>6.6 ft (2 m)	NOV-APR	MAY	JUN-SEP	OCT
Occurrence (%)	1	0	< 1	< 1
Average Duration (hr)	7	NA	8	12
Period Max Energy (sec)	11	NA	10	11

MARSEILLE POINT 2:	WINTER	SPRING	SUMMER	AUTUMN
>3.3 ft (1 m)	NOV-APR	MAY	JUN-SEP	OCT
Occurrence (%)	2	< 1	< 1	< 1
Average Duration (hr)	8	6	8	12
Period Max Energy (sec)	10	10	9	11
>6.6 ft (2 m)	NOV-APR	MAY	JUN-SEP	OCT
Occurrence (%)	< 1	0	0	0
Average Duration (hr)	6	NA	NA	NA
Period Max Energy (sec)	12	NA	NA	NA

SEASONAL SUMMARY OF HAZARDOUS WEATHER CONDITIONS

The location of Marseille at the southern end of the Rhone Valley exposes the port to the full force of strong Mistral (northerly) winds. Also, because of the harbor's shape, winds and seas from the southwest quadrant will affect the port.

WINTER (November thru February):

* Mistral winds of 20 kt frequent, 30 kt not uncommon and 55 kt on occasion.
* Mistral strongest and more frequent late in season.
* Moving ship close to shoreline will reduce fetch length thus reducing wave heights, but not wind speeds.
* Southwesterly winds are perpendicular to quays and tend to push vessels off moorings.

SPRING (March thru May):

* Mistral events greater than 30 kt occur 3-4 days/month.
* Southwesterlies occur more often than Mistral.

SUMMER (June thru September):

* Mistral is less intense and less frequent.

AUTUMN (October):

* Short transition season with winter-like weather the norm by end of month.

NOTE: For more detailed information on hazardous weather conditions see previous Summary Table in this section and Hazardous Weather Summary in Section 3.

REFERENCES

Hydrographer of the Navy, 1965: Mediterranean Pilot, Volume II. Published by the Hydrographer of the Navy, London, England.

3. GENERAL INFORMATION

This section is intended for Fleet meteorologists/oceanographers and staff planners. Paragraph 3.5 provides a general discussion of hazards and Table 3-5 provides a summary of vessel locations/situations, potential hazards, effect-precautionary/evasive actions, and advance indicators and other information about potential hazards by season.

3.1 Geographic Location

The Port of Marseille is located at 43°20'N 05°20'E on the southern coast of France (Figure 3-1).

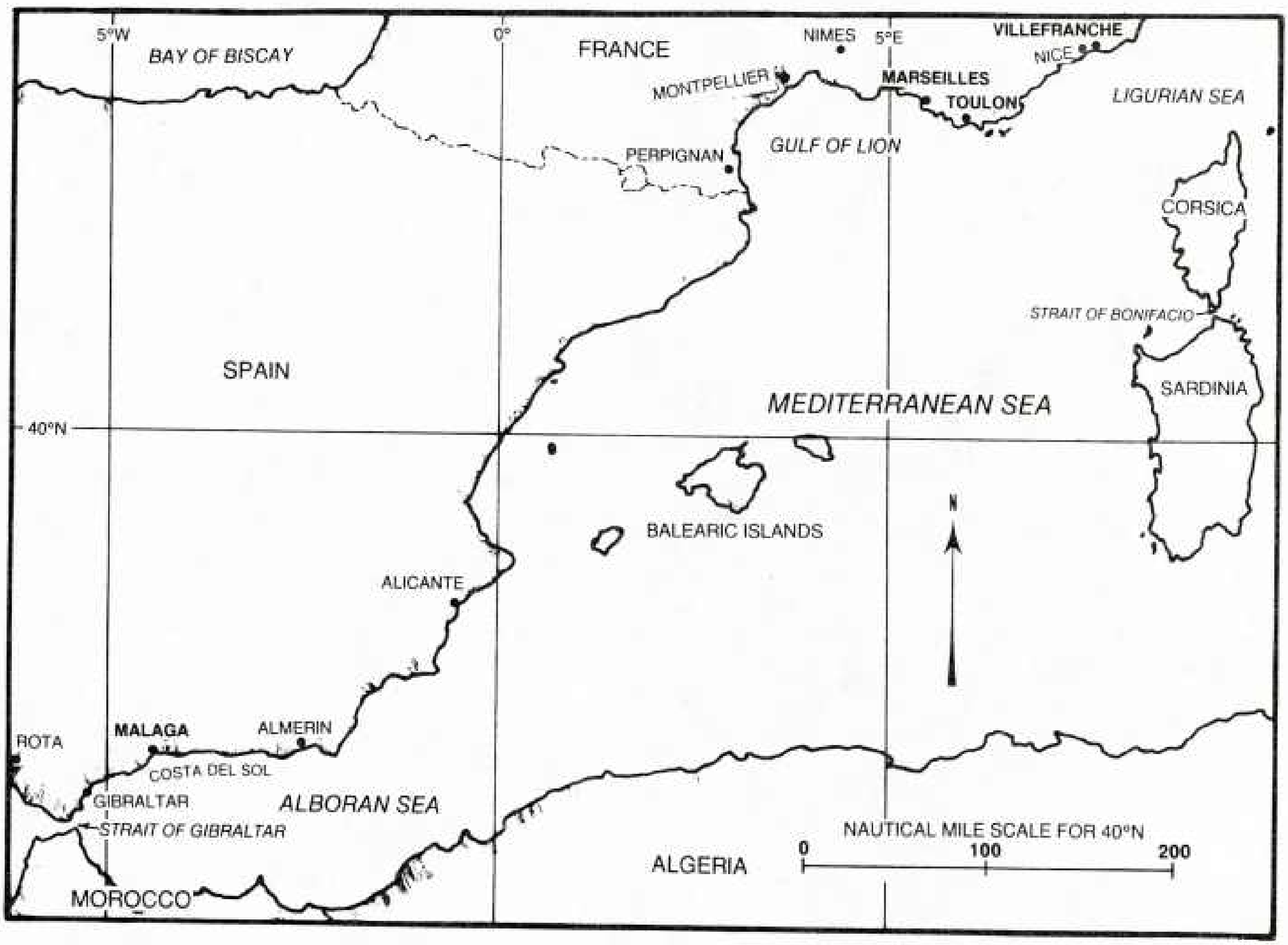

Figure 3-1. Western Mediterranean Sea.

The Port of Marseille is well protected from waves from the open ocean, but is exposed to winds. The orientation of the Port (Figure 3-2) minimizes the impact of the strongest wind--the northwesterly Mistral--to the extent that normal port operations in the inner harbor are carried out with little disruption. Winds from other directions do affect port operations.

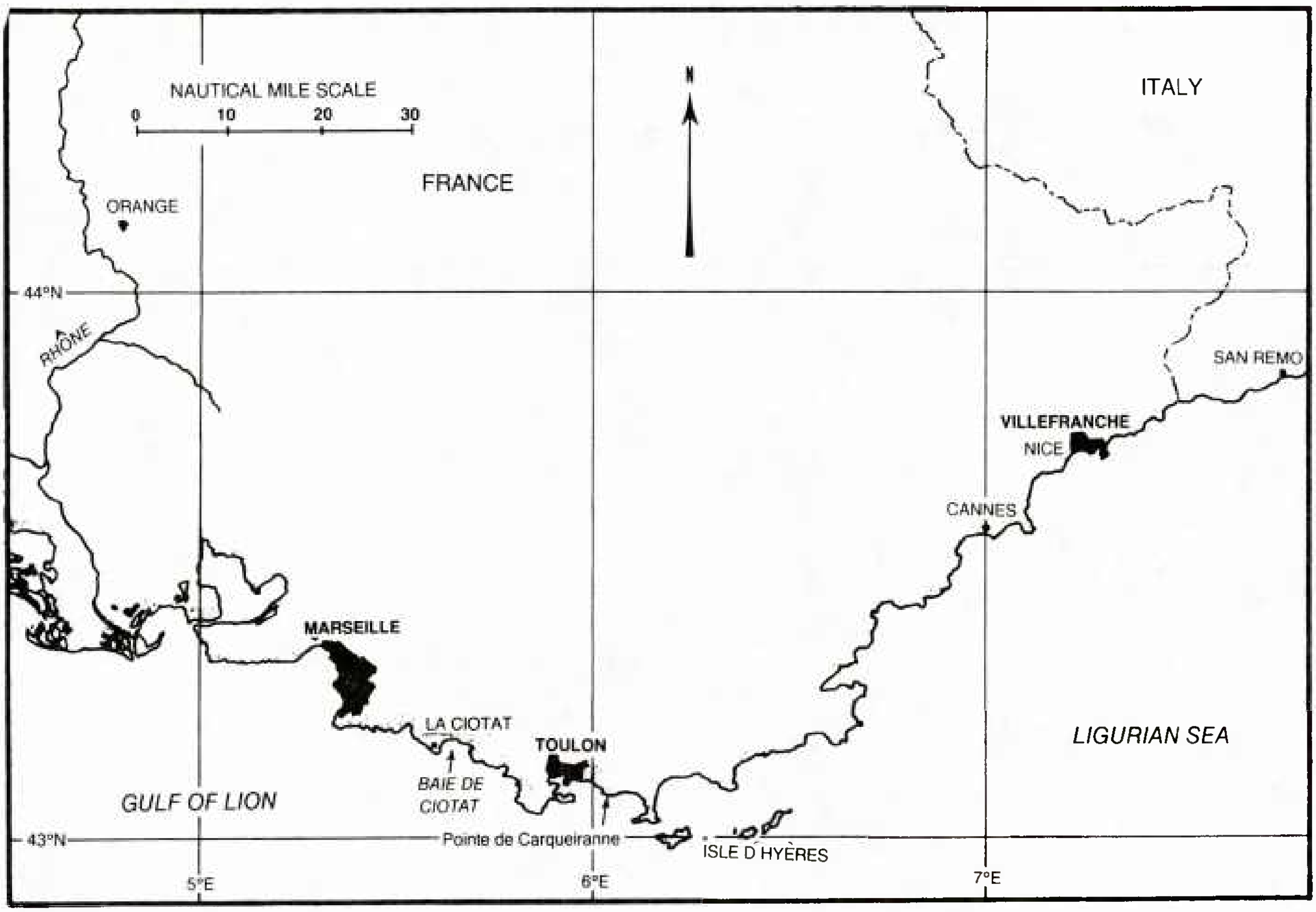

Figure 3-2. Ports-of Marseille, Toulon, Villefranche.

The harbor is situated on Rade de Marseille (Roadstead of Marseille) on the east and northeast side of the Gulf of Marseille (Golfe de Marseille). The Port extends about 3 3/4 mi along the coast between Mouripiane and Pointe du Pharo (Figure 3-3).

The inner harbor is composed of a series of basins which are sheltered from seaward by a 30 ft (9.1 m) high breakwater. Of primary interest to this discussion is the northern part of the Port, Nouveau Port, comprised of Avant Port Nord at the northern entrance, and the following basins: Bassin Mirabeau, Bassin Leon Gourret (Darse Sud), Bassin du Président Wilson, Bassin de la Pinède, Bassin National, and Bassin de la Gare Maritime (Figure 3-3).

The Port of Marseille is essentially surrounded by terrain or man-made structures. The northeast side of the port is protected by the French land mass with 2000-3200 ft (606-907 m) elevations within 15 mi of the coasts. The southwest side of the elongated port is defined by a long breakwater which extends the length of the port.

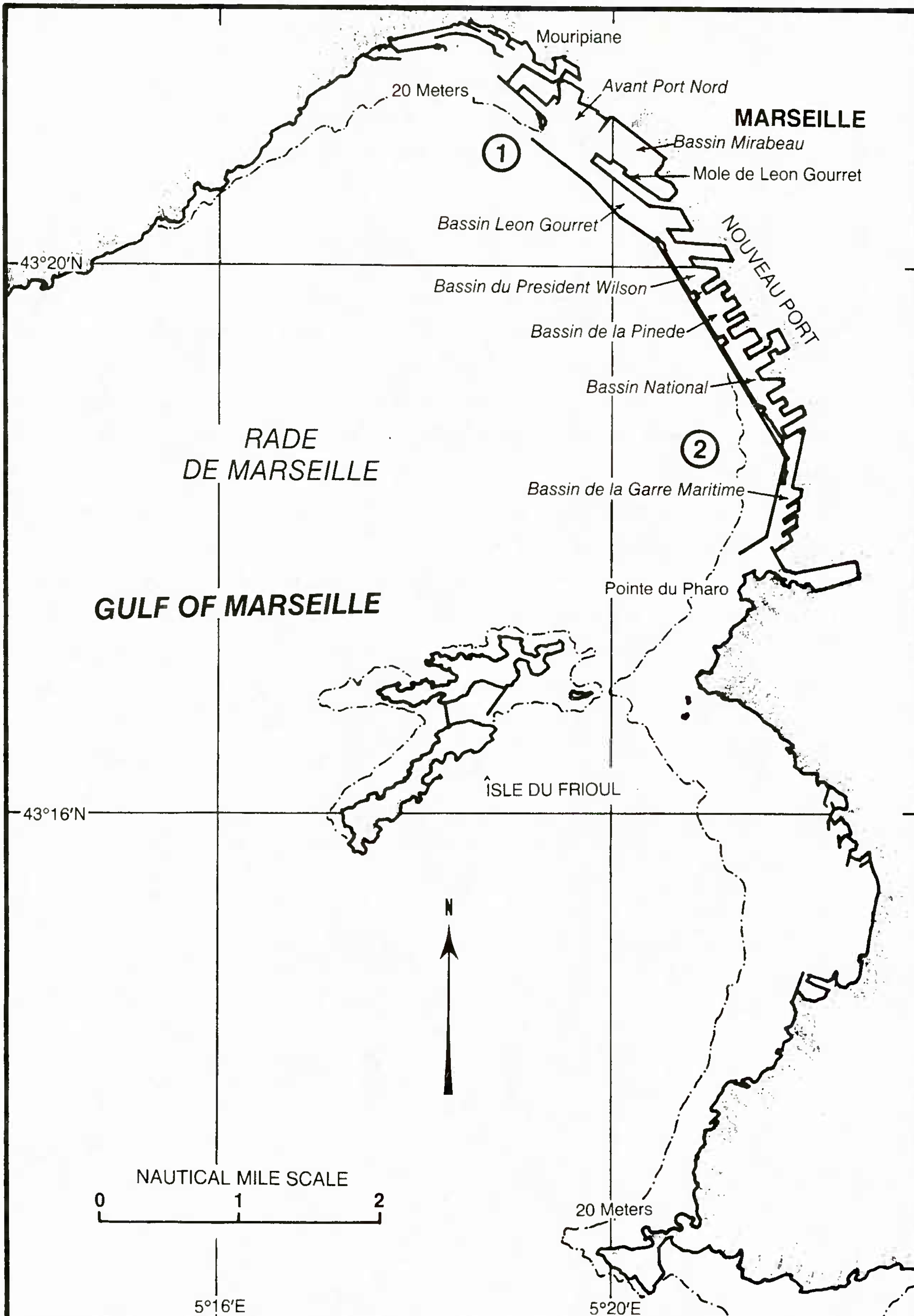

Figure 3-3. Port of Marseille.

3.2 Qualitative Evaluation of Harbor as a Haven

The Gulf of Marseille is bordered by the French landmass from northwest clockwise through southeast. Due to the topography of the region, however, it is only partially shielded from the effects of winds from the eastern semicircle. Marseille is located in the Rhône delta at the south end of the Rhône Valley, a long north-south rift between the Cevenees Mountains and the foothills of the French Alps. Cold, dry Mistral winds funnel southward through the valley and reach the Port of Marseille as northwesterlies. The northwest-southeast orientation of most of the quays in the Port mitigates the effect of the Mistral on vessels moored there. The fetch length is limited to about 3 n mi, but wind waves of 6 to 8 ft can be raised outside the breakwater.

The Gulf of Marseille is open to winds and seas from the southwest quadrant, but the Port is protected from southwesterly waves by a long, 30 ft (9.1 m) high breakwater that extends the length of the inner harbor. The anchorage is in an unprotected location outside the breakwater southwest of Mole Leon Gourret. Bottom type and holding qualities are not specified.

3.3 Currents and Tides

In general, currents are negligible at the Port of Marseille. They are irregular and do not set in a constant direction in any season. A wind driven current will often precede the arrival of the wind (Hydrographer of the Navy, 1965).

Tides are also insignificant, with a change of about 1 ft (30 cm) being normal. Within Marseille harbor, "sudden changes in the sea level of as much as 8 inches" ... "sometimes occur, and at the same time, currents of short duration may be experienced in the basin entrances; this generally occurs during strong

onshore winds with a high sea." (Hydrographer of the Navy, 1965).

3.4 Visibility

Although overall visibility is generally poorest during daylight hours in the summer, climatology statistics show that the worst visibility conditions--less than 1 km (about 1/2 n mi)--occur most often between the months of October and March, with November having the highest frequency of occurrence. Upwelling, brought about by Mistral winds, causes fog to form along the coast.

3.5 Hazardous Conditions

The location of Marseille at the southern end of the Rhône Valley exposes the Port to the full force of strong Mistral winds. The configuration of the Gulf of Marseille also allows winds from the southwest quadrant to strike the Port area with their full open-ocean velocities.

Although uncommon, storms having tropical cyclone characteristics with fully developed eyes have been observed on at least three occasions in the Mediterranean Basin: 23-26 September 1969, 22-28 January 1982, and 26-30 September 1983. On the latter occasion the storm moved northwest from the Gulf of Gabes (on the southeast coast of Tunisia), through the Straits of Sicily, along the east coast of Sardinia, and into the Gulf of Genoa. Winds of 100 kt were observed near the eye while Cagliari, Sardinia reported winds of 60 kt. While the probability of such a storm striking Marseille is very slight, the meteorologist must be aware of the possibility.

A seasonal summary of various known environmental hazards that may be encountered in the Port of Marseille follows.

A. Winter (November through February)

As is the case with other parts of the northern Mediterranean Sea, the onset of the winter season brings strong winds to the Port of Marseille, accompanied by frequent precipitation and cool temperatures.

Because of the Port's proximity to the Rhône Valley, strong, cold, dry Mistral winds are a common wintertime phenomena. The following definition of a Mistral is attributed to A. Orieux and is taken from Digest of Selected Weather Problems of the Mediterranean, (Reiter, 1971). Orieux defines the Mistral (at Marignane (Marseille)), station number 07650, as "a wind with a direction between 280° and 360° and with a speed of 10 kt (5 m/s) or more. Both criteria have to be met for at least 6 consecutive hours. A Mistral period is considered terminated if either the speed criterion, or the direction criterion, or both are violated for a time interval of 6 hours or more."

According to Hydrographer of the Navy (1965), there is no generally agreed lower limit to the speed of a wind which may be described as a Mistral, but force 5 (17-21 kt) is frequently experienced, gale force (34-40 kt) is not uncommon, and force 11 (56-63 kt) is occasionally reached.

Polar and Arctic air penetrates into the Mediterranean basin through the Rhône Valley on one day in every three during winter (FWC, Rota, Spain, 1966). Gradually increasing in intensity and frequency of occurrence, Mistral events are strongest and most frequent late in the season. Records from Marignane (Marseille) show an average of about 5 Mistrals of 30 kt (15 m/s) or more and 1 Mistral of 40 kt (20 m/s) or more can be expected during the month of February. Although winds as high as force 11 (56-63 kt) have been observed (Hydrographer of the Navy, 1965), they pose only minimal problems to harbor operations. The quays in the Port are oriented northwest-southeast and thus are aligned with the Mistral wind flow. There is a slight tendency for ships to be pushed off their berths, but with normal

mooring the problem is not significant. Entering and leaving the harbor during a Mistral is also no major problem since the orientation of the entrance to Avant Port Nord aligns the vessel's longitudinal axis with the wind direction. The diurnal variation in the intensity of the Mistral results in maximum wind strengths occurring during the afternoon at Marseille and other coastal stations (Brody and Nestor, 1980). <u>NOTE</u>: This is contrary to what occurs over the sea where maximum winds tend to occur at night.

A strong Mistral can pose problems for ships anchored in the area outside the breakwater adjacent to Mole Leon Gourret. To avoid the worst effects of the Mistral, moving northwestward toward the shoreline is recommended.

The Gulf of Marseille is open to winds and seas from the southwest quadrant. The southwest wind may be called Marin, Aygalas, Marinada or other names depending on the location. They are most common during spring and autumn, with occasional winter occurrences. The effects of southwesterly seas on the inner harbor of the Port are lessened by the long breakwater which extends the length of the Port. Southwesterly winds tend to force vessels on/off their berths because the winds are perpendicular to the orientation of most quays. According to Brody and Nestor (1980), strong southwesterly winds are common in the region between the southern French coast and Corsica, and are associated with the early stages of lee cyclogenesis south of the Alps. Farther west, in the Gulf of Lion, the wind is called the Marin, with directions varying from southeast to southwest. Though less strong than the Mistral, the Marin can raise a heavy sea along the coast (Hydrographer of the Navy, 1965), making conditions in the anchorage difficult if not untenable.

The Mistral is normally accompanied by clear skies, but the cold front which often precedes the wind can bring rain and violent squalls. If the Mistral is shallow with a southerly flow at mid-levels, overrunning will cause cloudiness and rain. Rain may also be

associated with transient extratropical cyclones as they migrate eastward south of Marseille. On average, precipitation will be recorded at Marseille on 31 days during the four-month winter period, or on about one day out of four (Hydrographer of the Navy, 1965).

The mean minimum temperature during January, the coldest month, is about 34°F (1°C), and the mean of the lowest temperatures each year is 19°F (-7°C) (Hydrographer of the Navy, 1965). Consequently, wind chill (temperature combined with wind) can be very cold, and personnel working in exposed locations must take appropriate precautions. Table 3-1 can be used to determine wind chill for various temperature and wind combinations.

Table 3-1. Wind Chill. The cooling power of the wind expressed as "Equivalent Chill Temperature" (adapted from Kotsch, 1983).

Wind Speed		Cooling Power of Wind expressed as "Equivalent Chill Temperature"								
Knots	MPH	Temperature (°F)								
Calm	Calm	40	35	30	25	20	15	10	5	0
		Equivalent Chill Temperature								
3-6	5	35	30	25	20	15	10	5	0	-5
7-10	10	30	20	15	10	5	0	-10	-15	-20
11-15	15	25	15	10	0	-5	-10	-20	-25	-30
16-19	20	20	10	5	0	-10	-15	-25	-30	-35
20-23	25	15	10	0	-5	-15	-20	-30	-35	-45
24-28	30	10	5	0	-10	-20	-25	-30	-40	-50
29-32	35	10	5	-5	-10	-20	-30	-35	-40	-50
33-36	40	10	0	-5	-15	-20	-30	-35	-45	-55

B. Spring (March through May)

Spring is a windy and unsettled season in Marseille, noted for periods of stormy weather with Mistral conditions that alternate with a number of false

starts of settled summer-type weather (Brody and Nestor, 1980). Strong Mistrals (equal to or greater than 30 kt (15 m/s)) can be expected on 3 to 4 days of each month through May, while the average occurrence of 40 kt (20 m/s) or greater Mistrals is less than 1 per month. The prevailing wind direction is northwest, with a mean wind speed of 9 kt during the morning (0700Z) and 13 kt during the afternoon (1300Z) (Hydrographer of the Navy, 1965).

Cold fronts which precede Mistral events continue to bring rain and/or squally weather during passage. Extratropical cyclones, usually forming in the Balearic Sea off the east coast of Spain, occasionally move northward to the southern coast of France and bring rain and strong southerly winds to the Marseille area. Migrating extratropical cyclones moving eastward south of Marseille can also bring rain and southerly winds to the region.

As the season progresses, west and southwest winds occur with increasing frequency during the afternoon hours, indicating the increasing impact of a sea breeze regime in the local area. Sea breeze velocities are relatively light and do not pose significant problems to harbor operations.

Temperatures moderate gradually throughout the season. Wind chill remains a factor during strong wind situations until late in the season.

C. Summer (June through September)

Summer is a period of relatively warm, dry, and settled weather along the south coast of France. Although Mistral conditions associated with cold outbreaks are still common near the coast of southern France, they are less frequent and weaker than those in other seasons. Mistrals of 30 kt (15 m/s) or greater can be expected on 1 to 2 days in each of the seasons 4 months, and those of 40 kt (20 m/s) are rare occurrences. During the summer months, the Mistral winds tend be be strongest in the late morning, rather than during the afternoon.

Upper-level westerlies and the associated storm track is moved northward during summer, so extratropical cyclones and associated wind and weather are not common.

Afternoon sea breezes often occur as mean daily maximum temperatures reach 84°F (29°C).

D. Autumn (October)

The autumn season is brief, usually lasting only for the month of October, and is characterized by an abrupt change to winter-type weather (Brody and Nestor, 1980).

Northwesterly winds become more dominant as Mistral frequency increases. Southwesterly winds also become more common during autumn as the extratropical storm track moves southward. Precipitation amount is the highest of the year, with an average of 3 inches (76 mm) for the month. Temperatures show significant decreases from those of September, but wind chill is not usually a factor until winter.

3.6 Harbor Protection

As discussed below, the inner harbor of the Port of Marseille is well protected from waves, but is exposed to winds. The anchorage outside the breakwater is vulnerable to both.

3.6.1 Wind and Weather

Adjacent terrain affords only limited protection to the Port area. The eastern semicircle is mountainous and serves to reduce the force of strong easterly winds (Lombarde). Lombarde winds come from the high Alps, becoming violent in winter (in the mountains) and form snow drifts in the mountain valleys. The topography of the land areas near the Port in the western semicircle, the directions from which the strongest winds emanate, is mostly low lying and unprotected. Mistral winds impact the Port with full force, as do south and southwesterly winds which precede fronts and extratropical cyclones. These winds can cause difficulty for ships anchored outside the quays. The northwest-southeast orientation

of the quays in the Port of Marseille aligns moored vessels with the Mistral winds.

There is a strong diurnal wind variation at the fleet anchorage during a Mistral, with maximum winds occurring in the afternoon and minimum winds reached shortly after midnight (Brody and Nestor, 1980). According to Hydrographer of the Navy (1965) anchorage in Rade de Marseille "is not recommended as it does not afford safe protection from easterly winds in winter or from the sudden changes of wind."

3.6.2 Waves

The inner harbor at Marseille is almost totally protected from significant wave action by the long, 30 ft high breakwater positioned along its western side. Wind waves generated by northwesterly winds can pass through the entrance to Avant Port Nord, but do not significantly affect inner-harbor operations. Small boating to/from vessels at anchor outside the breakwater are adversely affected by wave action with any strong wind from the western semicircle.

With west to northwest winds in both the Gulf of Lion and at the fleet anchorage, westerly swell is experienced at the anchorage. When the wind direction becomes more northerly in the Gulf of Lion, the swell diminishes. Note that according to Brody and Nestor (1980), northwest winds of 35 kt gusting to 45-50 kt at the anchorage can produce wind waves of 6-8 ft even though the fetch to the northwest of the anchorage is only 3 n mi. These extreme heights were not verified in this study and are about double the JONSWAP model values given in Table 3-4 for a 5 n mi fetch. In addition, the fetch length of 5 n mi vice 3 n mi is based on the fetch length to the west-northwest of the anchorage point 2 location as shown in Figure 3-3.

Table 3-2 provides the shallow water wave conditions at the two designated points when deep water swell enters the harbor.

Example: Use of Table 3-2.

For a deep water wave condition of:

8 feet, 12 seconds, from 180°

The approximate shallow water wave conditions are:

Point 1: 2-3 feet, 12 seconds, from 205°
Point 2: 1-2 feet, 12 seconds, from 215°

Table 3-2. Shallow water wave directions and relative height conditions versus deep water period and direction (see Figure 3-3 for location of the points).

FORMAT: Shallow Water Direction
Wave Height Ratio: (Shallow Water/Deep Water)

MARSEILLE POINT 1 (Near Northern Harbor Entrance) 120 ft depth

Period (sec)	6	8	10	12	14	16
Deep Water Direction	Shallow Water Direction and Height Ratio					
150°	185° .4	190° .4	200° .3	210° .3	215° .3	215° .3
180°	190° .5	190° .3	205° .1	205° .3	205° .4	205° .4
210°	210° 1.0	210° .9	210° .6	215° .6	215° .8	205° .5
240°	240° 1.0	240° .7	240° .5	240° .4	230° .4	235° .7
270°	260° .6	250° .5	245° .4	245° .3	240° .3	240° .3

MARSEILLE POINT 2 (Fleet Anchorage) 96 ft depth

Period (sec)	6	8	10	12	14	16
Deep Water Direction	Shallow Water Direction and Height Ratio					
180°	190° .3	200° .3	200° .3	215° .2	225° .2	240° .2
210°	185° .4	200° .3	200° .3	200° .2	215° .2	235° .2
240°	240° .3	250° .3	250° .2	255° .2	260° .1	260° .1
270°	265° .5	265° .4	260° .3	260° .3	260° .2	265° .2

Situation specific shallow water wave conditions resulting from deep water wave propagation are given in Table 3-2 while the seasonal climatology of wave conditions in the harbor resulting from the propagation of deep water waves into the harbor are given in Table 3-3. If the actual or forecast deep water wave conditions are known, the expected conditions at the two specified harbor areas can be determined from Table 3-2. The mean duration of the condition, based on the shallow water wave heights, can be obtained from Table 3-3.

Example: Use of Tables 3-2 and 3-3.

The forecast for wave conditions tomorrow (winter case) outside the harbor are:

8 feet, 14 seconds, from 210°

Expected shallow water conditions and duration:

	Point 1	Point 2
height	6-7 feet	1-2 feet
period	14 seconds	14 seconds
direction	from 215°	from 215°
duration	9-11 hours	NA

Interpretation of the information from Tables 3-2 and 3-3 provide guidance on the local wave conditions expected tomorrow at the various harbor points. The duration values are mean values for the specified height range and season. Knowledge of the current synoptic pattern and forecast/expected duration should be used when available.

Possible applications to small boat operations are selection of the mother ships anchorage point and/or areas of small boat work. The condition duration information provides insight as to how long before a change can be expected. The local wave direction information can be of use in selecting anchorage configuration and related small boat operations, including tending activities.

Table 3-3. Shallow water climatology as determined from deep water wave propagation. Percent occurrence, average duration or persistence, and wave period of maximum energy for wave height ranges of greater than 3.3 ft (1 m) and greater than 6.6 ft (2 m) by climatological season.

MARSEILLE POINT 1:	WINTER	SPRING	SUMMER	AUTUMN
>3.3 ft (1 m)	NOV-APR	MAY	JUN-SEP	OCT
Occurrence (%)	11	5	5	8
Average Duration (hr)	10	9	10	16
Period Max Energy (sec)	9	9	9	9
>6.6 ft (2 m)	NOV-APR	MAY	JUN-SEP	OCT
Occurrence (%)	1	0	< 1	< 1
Average Duration (hr)	7	NA	8	12
Period Max Energy (sec)	11	NA	10	11

MARSEILLE POINT 2:	WINTER	SPRING	SUMMER	AUTUMN
>3.3 ft (1 m)	NOV-APR	MAY	JUN-SEP	OCT
Occurrence (%)	2	< 1	< 1	< 1
Average Duration (hr)	8	6	8	12
Period Max Energy (sec)	10	10	9	11
>6.6 ft (2 m)	NOV-APR	MAY	JUN-SEP	OCT
Occurrence (%)	< 1	0	0	0
Average Duration (hr)	6	NA	NA	NA
Period Max Energy (sec)	12	NA	NA	NA

Local wind wave conditions are provided in Table 3-4 for Marseille points 1 and 2. The fetch lengths are specifically for points 1 and 2. The time to reach the fetch limited height assumes an initial flat ocean. With a pre-existing wave height, the times are shorter.

Table 3-4. Gulf of Marseille. Local wind waves for fetch limited conditions at points 1 and 2 (based on JONSWAP model).

Point 1.

Format: height (feet)/period (seconds)
time (hours) to reach fetch limited height

Direction and Fetch Length (n mi) \ Local Wind Speed (kt)	18	24	30	36	42
S 3 n mi	<2 ft	<2 ft	2/3 1	2/3 1	2-3/3 1
SW 120 n mi	5/7 7	8/8 8-9	8/9 8	10/9-10 7-8	9/10 7

Point 2.

Direction and Fetch Length (n mi) \ Local Wind Speed (kt)	18	24	30	36	42
WNW 5 n mi	<2 ft	2/3-4 1	2-3/3-4 1	3/3-4 1-2	3-4/3-4 1
W 80 n mi	3/7 7	4/7-8 7	4/8 6-7	4/8-9 6	5/9 5-6

Example: Small boat wave forecasts for Point 2 (based on the assumption that swell is not a limiting condition).

Forecast for Tomorrow:

Time	Wind (Forecast)	Waves (Table 3-4)
prior to 0700 LST	light and variable	< 1 ft
0700 to 1200	W 8-10 kt	< 2 ft
1200 to 2000	W 22-26 kt	building to 4 ft at 7-8 sec by 1900

Interpretation: Assuming that the limiting factor is waves greater than 3 feet, small boat operations will become marginal by 1800 and restricted before 1900.

Combined wave heights are computed by finding the square root of the sum of the squares of the wind wave and swell heights. For example, if the wind waves were 3 ft and the swell 8 ft the combined height would be about 8.5 ft.

$$\sqrt{3^2 + 8^2} = \sqrt{9 + 64} = \sqrt{73} \approx 8.5$$

Note that the increased height is relatively small. Even if the two wave types were of equal height the combined heights are only 1.4 times the equal height. In cases where one or the other heights are twice that of the other, the combined height will only increase over the larger of the two by 1.12 times (10 ft swell and 5 ft wind wave combined results in 11.2 ft height).

3.6.3 Wave Data Uses and Considerations

Local wind waves build up quite rapidly and also decrease rapidly when winds subside. The period and therefore length of wind waves is generally short relative to the period and length of waves propagated into the harbor (see Appendix A). The shorter period and

length result in wind waves being characterized by choppy conditions. When wind waves are superimposed on deep water waves propagated into shallow water, the waves can become quite complex and confused. Under such conditions, when more than one source of waves is influencing a location, tending or joint operations can be hazardous even if the individual wave train heights are not significantly high. Vessels of various lengths may respond with different motions to the diverse wave lengths present. The information on wave periods, provided in the previous tables, should be considered when forecasts are made for joint operations of various length vessels.

3.7 Protective/Mitigating Measures

3.7.1 Sortie/Remain in Port

Due to the protection provided by the extensive breakwater and the alignment of the quays with the direction of Mistral winds, the inner harbor is deemed safe for ships using normal mooring. Sorties are not required to evade commonly encountered strong winds or high waves. In the extremely rare circumstance when a tropical cyclone would be forecast to impact the harbor, leaving the Port and evading the storm at sea is recommended.

3.7.2 Moving to New Anchorage

Vessels anchored outside the breakwater may need to move northwestward in Rade de Marseille to reduce fetch length and thereby reduce the impact of Mistral winds. CAUTION: Shallow depths exist and care must be taken to avoid hazarding the vessel. If south to southwesterly winds and/or waves are adversely affecting the anchorage, vessels should leave the anchorage and either stay at sea until the waves subside or move to the anchorage at Toulon or more protected coastal waters east of Iles d'Hyères.

3.7.3 Scheduling

The 984 ft (300 m) wide entrance to the Port of Marseille (Avant Port Nord) is open to the northwest, allowing inbound/outbound units to remain aligned with the direction of the Mistral winds as they enter/leave the Port. As a result, ships can enter/depart the inner harbor during a Mistral with minimal wind problems. If the strongest Mistral winds are to be avoided, an early morning arrival or departure is recommended since the winds are strongest during afternoon hours.

3.8 Indicators of Hazardous Weather Conditions

Although the design of the Port of Marseille minimizes the potential problems posed by strong Mistral winds and other hazards, it is advisable to be aware of impending conditions. The following guidelines have been extracted from various sources and are intended to provide the insight necessary to enable the meteorologist to anticipate the onset, duration, intensity, and extent of hazardous weather conditions. Since the primary hazard is the Mistral, much of the following addresses that phenomenon, and is taken from Brody and Nestor's document, Regional Forecasting Aids for the Mediterranean Basin (1980).

3.8.1 Mistral

1. Causes

The Mistral is the result of a combination of the following factors:

(a) The basic circulation that creates a pressure gradient from west to east along the coast of southern France. This pressure gradient is normally associated with Genoa cyclogenesis.

(b) A fall wind effect caused by cold air associated with the Mistral moving downslope as it approaches the southern coast of France and thus increasing the wind speed.

(c) A jet-effect wind increase caused by the orographic configuration of the coastline. This phenomenon is observed at the entrance to major mountain gaps such as the Carcassone Gap, Rhône Valley, and Durance Valley. It is also observed in the Strait of Bonifacio between Corsica and Sardinia.

(d) A wind increase over the open water resulting from the reduction in the braking effect of surface friction (as compared to the braking effect over land).

Mistrals are observed in association with three particular upper level (500 mb) large-scale flow patterns. These flow patterns are classified as types A, B, and C by the British Air Ministry (1962).

Type A. A blocking ridge in the eastern Atlantic and a long-wave trough over Europe produces a strong northwesterly flow over western France. This is a meridional flow situation.

Type B. A blocking ridge extends northeastward from the eastern Atlantic over northern Europe and a low pressure belt covers the Mediterranean. Meridional flow predominates.

Type C. A series of depressions dominates the European mid-latitudes, and westerly winds prevail over the Mediterranean. This is a zonal-flow situation.

2. Onset

The following guidelines for forecasting the onset of a Mistral have been extracted from Brody and Nestor (1980).

In association with a Type A large-scale flow pattern:

(a) Forecast the start of a Mistral within 48 hr when a surface frontal trough is located

just south of Iceland and is backed by an extremely strong surge of cold air to the east of Greenland. (Note: The long-wave ridge axis is west of Iceland: this rule is biased toward established rather than developing patterns).

(b) Forecast the start of a Mistral within 24 hr when the frontal and 500 mb short-wave troughs extend across southern (or southeastern) England and the Bay of Biscay, and the short-wave ridge is located over Spain and France. (Note: The long-wave ridge axis is west of Iceland: This rule is biased toward established rather than developing patterns).

(c) A Mistral will occur if the 500 mb winds over England or Ireland are northwesterly 50 kt or more.

(d) A Mistral will start when the 500 mb short-wave arrives over Perpignan.

A Mistral is likely to occur with a Type A situation when: (1) the long wave trough is over or just past the south coast of France; and (2) a northwesterly (west through north-northeast) current with maximum speed of at least 50 kt at 500 mb is so oriented that it points toward the Gulf of Lion.

In association with a Type B large-scale flow pattern, forecast the start of a Mistral in 24 hr when; (1) the 500 mb trough moves over or just south of the south coast of France; and (2) the associated surface low appears in or near the Gulf of Genoa.

In association with a Type C large-scale flow pattern:

(a) Forecast the start of a Mistral within 48 hr when (1) a surface frontal trough and upper short-wave trough are 24° of longitude to the west of the Gulf of Lion, (2) the short-wave ridge is 12° west, and (3) both are progressing at a speed of 12° per day. (Note: The "rule of thumb" in this case is that these short-wave ridges and troughs replace each other in 24 hr, i.e., there is a tendency toward a 48 hr periodicity of frontal systems moving into France as long as the

high-index circulation is maintained. Mistrals in this situation must be short-lived.

(b) In association with a Type C large-scale flow pattern, forecast the start of a Mistral within 24 hr when the surface and 500 mb short-wave troughs extend from the Irish Sea southward over Portugal, and the short-wave ridge is over southern France. (Note: The pattern is poorly defined in this high-index situation.)

(c) In association with a Type C large-scale flow pattern, a Mistral will occur if a deepening 500 mb trough moves over the south coast of France and is followed by a 500 mb ridge building at about the longitude of Ireland and Spain.

(d) In association with a Type C large-scale flow pattern, a Mistral will start when a northwesterly jet stream arrives over the Bay of Biscay.

The synoptic situations for the following guidelines vary.

(a) If a cutoff low as seen at 500 mb forms over northeast France and produces a northwesterly flow at 500 mb over the south coast, a Mistral may occur even though 500 mb wind speeds do not reach 50 kt and the jet axis is located far to the west and south.

(b) A Mistral generally sets in when the surface front or trough passes Perpignan (07747), or the 500 mb trough passes Bordeaux (07510). (Note: These two events are expected to occur nearly simultaneously.)

(c) Genoa lows occur almost simultaneously with the onset of the Mistral in the Gulf of Lion, and they invariably form when conditions are right for a Mistral to occur.

(d) If a 500 mb trough extends from central Europe southward over North Africa, a surface low from Algeria may propagate northward, intensify in the Gulf of Genoa, and initiate a Mistral.

(e) The Mistral will start when one of three surface pressure differences is achieved:

Perpignan-Marignane (Marseille), 3 mb; Marignane-Nice, 3 mb; or Perpignan-Nice, 6 mb. A difference usually occurs from 0 to 24 hr after a closed Genoa low appears, but it occasionally occurs earlier.

(f) Wave clouds, such as observed on high-resolution Defense Meteorological Satellite Program (DMSP) satellite imagery, are observed over the Massif Central of southern France approximately 6 hr before the start of a Mistral.

(g) Lus La Croix Haute (07587) will provide a 2-3 hr advance notice of Mistral onset. This wind speed report will closely approximate the wind speed in the Gulf. (Note: Usefulness of this station is limited by the fact it only reports every 3 hr.)

(h) Orange (07579) gives a good 3-4 hr warning of a gale force Mistral when winds at this station increase to 25 kt northwesterly. Hourly reports are available from this station.

(i) By observing changes in the normally strong afternoon sea breeze (east-southeasterly) direction at Perpignan, it is possible to forecast the beginning of a Mistral in the Gulf of Lion. If, at this station, the wind shifts northerly with speeds increasing to 25-30 kt and the temperature drops at least 3°F, a strong Mistral (40-50 kt) will be blowing in the Gulf of Lion within 6 hr.

(j) The probability of Mistral occurrence is greatest (correlation coefficient, $r = 0.62$) if the 500 mb wind direction at Bordeaux is 330°-340° or 040°-050°, when the 500 mb trough reaches Nimes (07645). The probability decreases rapidly as direction changes either to the west or east from the 330°-050° band.

(k) The probability of Mistral occurrence with a blocking pattern is greatest ($r = 0.30$) if, at the time the trough reaches Nimes (07645), the Nimes height deviation from normal is about +200 m. For

progressive systems, the probability increases from r = 0.26 for deviations of +75 m to r = 0.98 for deviations of -350 m.

(l) The probability of Mistral occurrence is greatest when the 850 mb wind direction over Nimes is from 350°. It decreases with winds east or west of 350°, reaching near zero for winds from 240° and 090°.

(m) The probability of Mistral occurrence increases with the north component of the 850° mb wind at Nimes, reaching r = 0.93 for 50 kt.

3. <u>Intensity</u>

Although gusts of 70 kt in strong Mistrals are experienced, the proportion of days when a Mistral reaches gale force on the coast is small. At Perpignan and Marseille the number of days when a Mistral reaches gale force is of the order of 10 to 15 in a year, (Hydrographer of the Navy, 1965).

The following guidelines are extracted from Brody and Nestor (1980).

(a) Strongest winds associated with a Mistral do not occur until after the passage of the upper-level (500 mb) trough. This occurs well after the surface cold frontal passage.

(b) Forecast Mistral winds to increase during a Type A large-scale flow pattern aloft 24 hr after a new cold front or minor trough appears in the northwest current over southern England, and the maximum speed at 500 mb in the current increases at least 10 kt while the inflection point retrogrades or remains stationary; or with the passage of the new cold front or minor trough.

(c) Satellite observations indicating a strong Mistral will exhibit the following features: cloudy over France and clear over the water area south of the 1,000 ft water depth contour; clear over the Gulf of Lion but a cloud mass, parallel to the coast, lying 75-150 n mi offshore; wispy cloud streaks extending from 315° to 360° into offshore clouds. See <u>NTAG Vol 2</u> pg

2D-8 (NEPRF, 1977) and NTAG Vol. 3 pg 2B-17 (NEPRF, 1980) for satellite case studies of Mistral events.

(d) Wave clouds extending from Sardinia to Tunisia, viewed on satellite imagery, are generally associated with gale force Mistral situations.

(e) Maximum Mistral winds occur when the surface isobars are at an angle of 30° to the valleys of either the Garonne, the Rhône or the Durance with low pressure to the southeast.

(f) Use the information below to estimate wind speed associated with a Mistral in the Gulf of Lion.

Pressure Difference (mb)	Perpignan* (station 07747) and Nice (station 07690)	Perpignan* and Marignane (station 07650)	Marignane** and Nice
3		30-35 kt	30-35 kt
4		40	40
5		45-50	45-50
6	30-35 kt		
8	40		
10	45-50		

* Highest pressure at Perpignan
** Highest pressure at Marignane

(g) A good indication of the intensity of a Mistral in the Gulf of Lion can be obtained by adding 10 kt to the wind speed reported by either Montpellier (07643) or Istres (07647).

(h) If the 500 mb winds reported at either Bordeaux (07510) or Brest (07110) are northwesterly at 65 kt or greater, storm warnings instead of gale warnings are indicated for the Gulf of Lion.

(i) Wind speeds over open water during a Mistral will be approximately double those measured at Perpignan or Marignane (Marseille) except in storm conditions, when the ratio will be lower.

4. Duration

Mistral occurrences average 110 days a year at Marseille (Hydrographer of the Navy, 1965). A strong Mistral may last for only a few hours, but on occasions for as many as 12 days without any important lulls. The most frequent length of an occurrence is about 3 1/2 days (Meteorological Office, 1962).

When clouds come from the east the Mistral will stop and east winds will start.

When strong winds and fractocumulus clouds come from the north instead of northwest, the Mistral will cease within 2 hours.

The following guidelines are taken from Brody and Nestor (1980).

In association with a Type A large-scale flow pattern, (described above under Mistral causes), surface winds usually decrease, i.e., the Mistral ceases, when the jet axis moves eastward and an anticyclonic regime is established. This rule reflects the control on the surface pattern that is exercised by the upper air pattern.

The Mistral will cease when the cyclonic regime at the surface gives way to an anticyclonic regime. Indications of this change are:

(a) The surface wind direction becomes north to northeast.

(b) The 500 mb ridge begins to move over the area.

(c) High pressure at the surface begins to move into the western basin of the Mediterranean.

(d) There is a change that reduces the pressure difference between France and the western basin.

Cold advection on the western flank of a blocking ridge over the eastern Atlantic may herald the breakdown of the long-wave pattern and hence, of the Mistral. This rule applies to Types A and B large-scale flow patterns where breakdown of the ridge, rather than eastward movement, results in cessation of the Mistral.

5. <u>Extent</u>

In the proximity of Marseille and the Rhône delta the local geography favors the Mistral, and this wind may develop here and produce what may be termed a "local Mistral" under a variety of pressure distributions which would not be conducive to the development of a "widespread Mistral" such as would affect the western Mediterranean generally. The orientation of the Rhône valley favors a northerly flow of air through the narrower parts. In the lower reaches the flow becomes northwesterly and this is the direction of the Mistral at Marseille. When the local Mistral is blowing, only the region around the Rhône delta, including Marseille, may be affected and the wind extends about 5 or 10 mi seaward. On other occasions, however, the Mistral may be widespread and may affect the whole of the Gulf of Lion and at times may extend even as far as the African coast and Malta. At such times it is common for the wind to be stronger in the Rhône delta-Marseille region than elsewhere. Eastward from Iles d'Hyères there is rapid decrease in the frequency and in the average force of the Mistral. It blows at times along all this coast but because of its reduced frequency and intensity it is not as strong here as around the Rhône delta, and the general climate of the French Riviera benefits from being sheltered from the stronger Mistral which is experienced farther west. Often, light easterlies are reported from Nice when strong northwesterlies are blowing at Marseille (Hydrographer of the Navy, 1965).

Alongshore pressure gradient is important in predicting Mistral intensity. When the difference is small the Mistral will stop. When a 10 mb difference exists between Toulon and Nice, the Mistral will spread eastward. With only a 2 mb difference between Marseille and Toulon, the Mistral will cease near Toulon.

The eastern boundary of the Mistral extends downwind from the western edge of the Alps through San Remo, Italy (Brody and Nestor, 1980).

6. Frequency

An analysis of 5 years of wind observations at Marseille (Marignane) showed that a moderate or strong Mistral (20 kt or more from directions between west-northwest and north-northwest) was reported in 6 percent of the observations at 0600, and in 11 percent of those at 1800. About a quarter of these reached speeds of 30 kt and above. At Marseille (Pomègues) northwesterly gales (32 kt and above) constitute 4 to 7 percent of the total wind observations in each of the months November to April decreasing to 1 to 3 percent in the intervening months (Hydrographer of the Navy, 1965).

7. Associated Weather

When fully established, the Mistral is usually accompanied by clear skies. However, rain (or in winter, snow) and violent squalls commonly accompany the cold front which precedes the Mistral. Where there is high ground near the coast, violent squalls can be expected in the lee during strong northwesterly winds. Baie de Ciotat (between Marseille and Toulon) is such a place (Hydrographer of the Navy, 1965).

Skies along the coast are usually clear. Precipitation is uncommon, except when the Mistral is shallow with a southerly flow of mid-levels that causes middle cloudiness and rain. Other exceptions are at the cold front associated with the onset of the Mistral and at secondary cold fronts associated with reintensification of Mistral conditions. However, as the cold air moves out over the warmer water, convective cloudiness does increase. Poor visibilities also have been reported up to a height of 30 m during cases of extremely strong Mistrals because of a layer of spray that extends above the water surface (Brody and Nestor, 1980).

3.8.2 Non-Mistral

1. When clouds come from the south to southeast, Toulon is more cloudy/rainy than Marseille. When clouds come from the southwest rain starts first at Marseille.

2. Marseille is dry during east to northeast flow while Toulon is wet.

3. A "Lombarde" (east wind) results in snow in the mountains.

4. The early stages of lee cyclogenesis south of the Alps commonly results in southwesterly winds of 30-40 kt in the region between the southern French coast and Corsica (Brody and Nestor, 1980).

3.9 Summary of Problems, Actions, and Indicators

Table 3-5 is intended to provide easy to use seasonal references for meteorologists on ships using the Port of Marseille. Table 2-1 (section 2) summarizes Table 3-5 and is intended primarily for use by ship captains.

Table 3-5. Potential problem situations at Port of Marseille - ALL SEASONS

VESSEL LOCATION/SITUATION	POTENTIAL HAZARD	EFFECT - PRECAUTIONARY/EVASIVE ACTIONS	ADVANCE INDICATORS AND OTHER INFORMATION ABOUT POTENTIAL HAZARD
1. Moored - single or nested. Strongest in late Winter & early Spring Weakest in Summer Autumn	a. Mistral wind - Common NW'ly wind. Strongest in afternoon, weakest just after midnight. Force 5 (17-21 kt) frequently experienced, force 8 (gale force, 34-40 kt) common, and force 11 (56-63 kt) reached occasionally. Occurs year-round but most common and strongest in late winter/early spring, weakest in summer. Commonly lasts 3-6 days but may be of shorter or longer duration.	a. Although Mistral winds can be quite strong, the orientation of the Port minimizes the effect of the winds on port operations. There is a slight tendency for vessels to be forced off their berths but normal mooring configurations are adequate to offset the effect of the wind. Minimize personnel exposure on weather decks during a strong event. Be aware of wind chill factor during winter and early spring.	a. There are many guidelines concerning the causes, onset, intensity, duration, extent, frequency and weather associated with Mistral. Refer to section 3.8.1 of the accompanying text for an extensive discussion.
Winter Spring Uncommon in Summer Autumn	b. SW'ly Wind - Caused by extratropical cyclones/frontal systems approaching Marseille area and lee cyclogenesis south of the Alps. Less strong than the Mistral, the wind may be called Marin or other local names. Most frequent in autumn and spring.	b. Wind blows perpendicular to quay orientation, resulting in moored vessels to be forced on/off their berths. Berths normally assigned U.S. vessels (115 and 116 in Bassin de la Penide, 119 in Bassin du Présidente Wilson, and 163 (carrier berth) in Bassin Mirabeau) are all on NE side of quays so vessels utilizing them would be forced off the berth. Doubling of mooring lines may be required to keep alongside/nested position secure. Minimize personnel exposure on weather decks during a strong event.	b. Watch for cyclogenesis which will place Marseille in southerly flow preceding the passage of the low pressure center, or approaching frontal system with associated steep pressure gradient at or south of Marseille's latitude.
2. Anchored.	ANCHORAGE IN RADE DE MARSEILLE "IS NOT RECOMMENDED AS IT DOES NOT AFFORD SAFE PROTECTION FROM EASTERLY WINDS IN WINTER OR FROM THE SUDDEN CHANGES OF WIND." (Hydrographer of the Navy, 1965)		
Strongest in late Winter & early Spring Weakest in Summer Autumn	a. Mistral wind - Common NW'ly wind. Strongest in afternoon, weakest just after midnight. Force 5 (17-21 kt) frequently experienced, force 8 (gale force, 34-40 kt) common, and force 11 (56-63 kt) reached occasionally. Occurs year-round but most common and strongest in late winter/early spring, weakest in summer. Commonly lasts 3-6 days but may be of shorter or longer duration. There is a strong diurnal wind variation at the fleet anchorage, with maximum winds occurring in the afternoon and minimum winds reached shortly after midnight.	a. Strong Mistral winds may cause vessels to drag anchor toward shallow water/breakwater SE of anchorage. Effect may be reduced by moving NW in Rade de Marseille. CAUTION: Be alert for shallow water. Minimize personnel exposure on weather decks during a strong event. Be aware of wind chill factor during winter and early spring.	a. There are many guidelines concerning the causes, onset, intensity, duration, extent, frequency and weather associated with Mistral. Refer to section 3.8.1 of the accompanying text for an extensive discussion.
Winter Spring Uncommon in Summer Autumn	b. SW'ly Wind/Waves - Caused by extratropical cyclones/frontal systems approaching Marseille area and lee cyclogenesis south of the Alps. Less strong than the Mistral, the wind may be called Marin or other local names. Most frequent in autumn and spring.	b. A strong event may cause vessels to drag anchor toward shallow water/breakwater NE of anchorage. Deployment of 2 anchors may provide adequate holding, but combined effects of wind and sea may dictate moving to Toulon anchorage or more protected waters east of Iles d'Hyères or to remain at sea until the wind/waves subside. Minimize personnel exposure on weather decks.	b. Watch for cyclogenesis which will place Marseille in southerly flow preceding the passage of the low pressure center, or approaching frontal system with associated steep pressure gradient at or south of Marseille's latitude.
Winter Spring	c. E'ly Wind - Called Lombarde and coming from the high Alps, the wind is violent in winter in the mountains, and causes drifting snow in mountain valleys. The winds cause difficulty for vessels in the anchorage.	c. A strong event may cause vessels to drag anchor. Deployment of 2 anchors may provide adequate holding, but strong winds may dictate moving to Toulon or other more protected waters or remain at sea until winds subside. Minimize personnel exposure on weather decks. Be aware of wind chill factor.	c. In winter or early spring, watch for a high pressure cell over France and central Europe, or with high pressure SE of Europe and low pressure to the NW, along with falling pressure over western France.

[redacted]

Table 3-5. (Continued)

VESSEL LOCATION/SITUATION	POTENTIAL HAZARD	EFFECT - PRECAUTIONARY/EVASIVE ACTIONS	ADVANCE INDICATORS AND OTHER INFORMATION ABOUT POTENTIAL HAZARD
3. Arriving/departing. Strongest in late Winter & early Spring Weakest in Summer Autumn	a. Mistral wind - Common NW'ly wind. Strongest in afternoon, weakest just after midnight. Force 5 (17-21 kt) frequently experienced, force 8 (gale force, 34-40 kt) common, and force 11 (56-63 kt) reached occasionally. Occurs year-round but most common and strongest in late winter/early spring, weakest in summer. Commonly lasts 3-6 days but may be of shorter or longer duration.	a. Although Mistral winds can be quite strong, the orientation of the entrance to Avant Port Nord (so the wind is essentially aligned with ship longitudinal axis) minimizes problems during entrance or exit. The same orientation of the quays minimizes the effect of the wind during deberthing, but slow SOA may create ship maneuvering problems as the vessel approaches/departs the quay. Arriving/departing at first light will normally result in less wind than will an afternoon evolution. Minimize personnel exposure on weather decks during a strong event. Be aware of wind chill factor during winter and early spring.	a. There are many guidelines concerning the causes, onset, intensity, duration, extent, frequency and weather associated with Mistral. Refer to section 3.8.1 of the accompanying text for an extensive discussion.
Uncommon in Winter Spring Summer Autumn	b. SW'ly Wind/Waves - Caused by extratropical cyclones/frontal systems approaching Marseille area and lee cyclogenesis south of the Alps. Less strong than the Mistral, the wind may be called Marin or other local names. Most frequent in autumn and spring.	b. Strong winds may raise heavy sea and swell outside the breakwater, making the approach to the entrance to Avant Port Nord difficult. The wind direction is essentially perpendicular to the longitudinal axis of inbound/outbound units in the harbor entrance and alongside the quays. Depending on wind velocity, berthing/deberthing may be difficult due to side forces imposed by the wind. Arrival/departure may need to be postponed until the wind subsides.	b. Watch for cyclogenesis which will place Marseille in southerly flow preceding the passage of the low pressure center, or approaching frontal system with associated steep pressure gradient at or south of Marseille's latitude.
4. Small boats. Strongest in late Winter & early Spring Weakest in Summer Autumn	a. Mistral wind - Common NW'ly wind. Strongest in afternoon, weakest just after midnight. Force 5 (17-21 kt) frequently experienced, force 8 (gale force, 34-40 kt) common, and force 11 (56-63 kt) reached occasionally. Occurs year-round but most common and strongest in late winter/early spring, weakest in summer. Commonly lasts 3-6 days but may be of shorter or longer duration. Associated wind waves may reach 6-8 ft outside the breakwater in a strong event.	a. Boating may be restricted to protected waters inside the breakwater.	a. There are many guidelines concerning the causes, onset, intensity, duration, extent, frequency and weather associated with Mistral. Refer to section 3.8.1 of the accompanying text for an extensive discussion.
Uncommon in Winter Spring Summer Autumn	b. SW'ly Wind/Waves - Caused by extratropical cyclones/frontal systems approaching Marseille area and lee cyclogenesis south of the Alps. Less strong than the Mistral, the wind may be called Marin or other local names. Most frequent in autumn and spring.	b. Boating may be restricted to protected waters inside the breakwater.	b. Watch for cyclogenesis which will place Marseille in southerly flow preceding the passage of the low pressure center, or approaching frontal system with associated steep pressure gradient at or south of Marseille's latitude.

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PORT VISIT INFORMATION

JUNE 1986. NEPRF meteorologists R. Fett and R. Picard met with the Duty Port Captain and French meteorologist Mr. Mayerson to obtain much of the information included in this port evaluation.

APPENDIX A

General Purpose Oceanographic Information

This section provides general information on wave forecasting and wave climatology as used in this study. The forecasting material is not harbor specific. The material in paragraphs A.1 and A.2 was extracted from H.O. Pub. No. 603, Practical Methods for Observing and Forecasting Ocean Waves (Pierson, Neumann, and James, 1955). The information on fully arisen wave conditions (A.3) and wave conditions within the fetch region (A.4) is based on the JONSWAP model. This model was developed from measurements of wind wave growth over the North Sea in 1973. The JONSWAP model is considered more appropriate for an enclosed sea where residual wave activity is minimal and the onset and end of locally forced wind events occur rapidly (Thornton, 1986), and where waves are fetch limited and growing (Hasselmann, et al., 1976). Enclosed sea, rapid onset/subsiding local winds, and fetch limited waves are more representative of the Mediterranean waves and winds than the conditions of the North Atlantic from which data was used for the Pierson and Moskowitz (P-M) Spectra (Neumann and Pierson 1966). The P-M model refined the original spectra of H.O. 603, which over developed wave heights.

The primary difference in the results of the JONSWAP and P-M models is that it takes the JONSWAP model longer to reach a given height or fully developed seas. In part this reflects the different starting wave conditions. Because the propagation of waves from surrounding areas into semi-enclosed seas, bays, harbors, etc. is limited, there is little residual wave action following periods of locally light/calm winds and the sea surface is nearly flat. A local wind developed wave growth is therefore slower than wave growth in the open ocean where some residual wave action is generally always

present. This slower wave development is a built in bias in the formulation of the JONSWAP model which is based on data collected in an enclosed sea.

A.1 Definitions

Waves that are being generated by local winds are called "SEA". Waves that have traveled out of the generating area are known as "SWELL". Seas are chaotic in period, height and direction while swell approaches a simple sine wave pattern as its distance from the generating area increases. An in-between state exists for a few hundred miles outside the generating area and is a condition that reflects parts of both of the above definitions. In the Mediterranean area, because its fetches and open sea expanses are limited, SEA or IN- BETWEEN conditions will prevail. The "SIGNIFICANT WAVE HEIGHT" is defined as the average value of the heights of the one-third highest waves. PERIOD and WAVE LENGTH refer to the time between passage of, and distances between, two successive crests on the sea surface. The FREQUENCY is the reciprocal of the period ($f = 1/T$) therefore as the period increases the frequency decreases. Waves result from the transfer of energy from the wind to the sea surface. The area over which the wind blows is known as the FETCH, and the length of time that the wind has blown is the DURATION. The characteristics of waves (height, length, and period) depend on the duration, fetch, and velocity of the wind. There is a continuous generation of small short waves from the time the wind starts until it stops. With continual transfer of energy from the wind to the sea surface the waves grow with the older waves leading the growth and spreading the energy over a greater range of frequencies. Throughout the growth cycle a SPECTRUM of ocean waves is being developed.

A.2 Wave Spectrum

Wave characteristics are best described by means of their range of frequencies and directions or their spectrum and the shape of the spectrum. If the spectrum of the waves covers a wide range of frequencies and directions (known as short-crested conditions), SEA conditions prevail. If the spectrum covers a narrow range of frequencies and directions (long crested conditions), SWELL conditions prevail. The wave spectrum depends on the duration of the wind, length of the fetch, and on the wind velocity. At a given wind speed and a given state of wave development, each spectrum has a band of frequencies where most of the total energy is concentrated. As the wind speed increases the range of significant frequencies extends more and more toward lower frequencies (longer periods). The frequency of maximum energy is given in equation 1.1 where v is the wind speed in knots.

$$f_{max} = \frac{2.476}{v} \qquad (1.1)$$

The wave energy, being a function of height squared, increases rapidly as the wind speed increases and the maximum energy band shifts to lower frequencies. This results in the new developing smaller waves (higher frequencies) becoming less significant in the energy spectrum as well as to the observer. As larger waves develop an observer will pay less and less attention to the small waves. At the low frequency (high period) end the energy drops off rapidly, the longest waves are relatively low and extremely flat, and therefore also masked by the high energy frequencies. The result is that 5% of the upper frequencies and 3% of the lower frequencies can be cut-off and only the remaining

frequencies are considered as the "significant part of the wave spectrum". The resulting range of significant frequencies or periods are used in defining a fully arisen sea. For a fully arisen sea the approximate average period for a given wind speed can be determined from equation (1.2).

$$\bar{T} = 0.285v \tag{1.2}$$

Where v is wind speed in knots and T is period in seconds. The approximate average wave length in a fully arisen sea is given by equation (1.3).

$$\bar{L} = 3.41\ \bar{T}^2 \tag{1.3}$$

Where $\bar{L}$ is average wave length in feet and $\bar{T}$ is average period in seconds.

The approximate average wave length of a fully arisen sea can also be expressed as:

$$\bar{L} = .67\text{"L"} \tag{1.4}$$

where "L" = $5.12T^2$, the wave length for the classic sine wave.

A.3 Fully Arisen Sea Conditions

For each wind speed there are minimum fetch (n mi) and duration (hr) values required for a fully arisen sea to exist. Table A-1 lists minimum fetch and duration values for selected wind speeds, values of significant wave (average of the highest 1/3 waves) period and height, and wave length of the average wave during developing and fully arisen seas. The minimum duration time assumes a start from a flat sea. When pre-existing

lower waves exist the time to fetch limited height will be shorter. Therefore the table duration time represents the maximum duration required.

Table A-1. Fully Arisen Deep Water Sea Conditions Based on the JONSWAP Model.

Wind Speed (kt)	Minimum Fetch/Duration (n mi) (hrs)	Sig Wave (H1/3) Period/Height (sec) (ft)	Wave Length (ft)[1,2] Developing/Fully /Arisen L X (.5) /L X (.67)
10	28 / 4	4 / 2	41 / 55
15	55 / 6	6 / 4	92 / 123
20	110 / 8	8 / 8	164 / 220
25	160 / 11	9 / 12	208 / 278
30	210 / 13	11 / 16	310 / 415
35	310 / 15	13 / 22	433 / 580
40	410 / 17	15 / 30	576 / 772

NOTES:

[1] Depths throughout fetch and travel zone must be greater than 1/2 the wave length, otherwise shoaling and refraction take place and the deep water characteristics of waves are modified.

[2] For the classic sine wave the wave length (L) equals 5.12 times the period (T) squared ($L = 5.12T^2$). As waves develop and mature to fully developed waves and then propagate out of the fetch area as swell their wave lengths approach the classic sine wave length. Therefore the wave lengths of developing waves are less than those of fully developed waves which in turn are less than the length of the resulting swell. The factor of .5 (developing) and .67 (fully developed) reflect this relationship.

A.4 Wave Conditions Within The Fetch Region

Waves produced by local winds are referred to as SEA. In harbors the local sea or wind waves may create hazardous conditions for certain operations. Generally within harbors the fetch lengths will be short and therefore the growth of local wind waves will be fetch limited. This implies that there are locally determined upper limits of wave height and period for each wind velocity. Significant changes in speed or direction will result in generation of a new wave group with a new set of height and period limits. Once a fetch limited sea reaches its upper limits no further growth will occur unless the wind speed increases.

Table A-2 provides upper limits of period and height for given wind speeds over some selected fetch lengths. The duration in hours required to reach these upper limits (assuming a start from calm and flat sea conditions) is also provided for each combination of fetch length and wind speed. Some possible uses of Table A-2 information are:

1) If the only waves in the area are locally generated wind waves, the Table can be used to forecast the upper limit of sea conditions for combinations of given wind speeds and fetch length.

2) If deep water swell is influencing the local area in addition to locally generated wind waves, then the Table can be used to determine the wind waves that will combine with the swell. Shallow water swell conditions are influenced by local bathymetry (refraction and shoaling) and will be addressed in each specific harbor study.

3) Given a wind speed over a known fetch length the maximum significant wave conditions and time needed to reach this condition can be determined.

Table A-2. Fetch Limited Wind Wave Conditions and Time Required to Reach These Limits (Based on JONSWAP Model). Enter the table with wind speed and fetch length to determine the significant wave height and period, and time duration needed for wind waves to reach these limiting factors. All of the fetch/speed combinations are fetch limited except the 100 n mi fetch and 18 kt speed.

Format: height (feet)/period (seconds)
duration required (hours)

Fetch \ Length \ (n mi)	Wind Speed (kt) 18	24	30	36	42
10	2/3-4 1-2	3/3-4 2	3-4/4 2	4/4-5 1-2	5/5 1-2
20	3/4-5 2-3	4/4-5 3	5/5 3	6/5-6 3-4	7/5-6 3
30	3-4/5 3	5/5-6 4	6/6 3-4	7/6 3-4	8/6-7 3
40	4-5/5-6 4-5	5/6 4	6-7/6-7 4	8/7 4	9-10/7-8 3-4
100	5/6-7[1] 5-6	9/8 8	11/9 7	13/9 7	15-16/9-10 7

[1] 18 kt winds are not fetch limited over a 100 n mi fetch.

An example of expected wave conditions based on Table A-2 follows:

WIND FORECAST OR CONDITION

An offshore wind of about 24 kt with a fetch limit of 20 n mi (ship is 20 n mi from the coast) is forecast or has been occurring.

SEA FORECAST OR CONDITION

From Table A-2: If the wind condition is forecast to last, or has been occurring, for at least 3 hours:

Expect sea conditions of 4 feet at 4-5 second period to develop or exist. If the condition lasts less than 3 hours the seas will be lower. If the condition lasts beyond 3 hours the sea will not grow beyond that developed at the end of about 3 hours unless there is an increase in wind speed or a change in the direction that results in a longer fetch.

A.5 <u>Wave Climatology</u>

The wave climatology used in these harbor studies is based on 11 years of Mediterranean SOWM output. The MED-SOWM is discussed in Volume II of the U.S. <u>Naval Oceanography Command Numerical Environmental Products Manual</u> (1986). A deep water MED-SOWM grid point was selected as representative of the deep water wave conditions outside each harbor. The deep water waves were then propagated into the shallow water areas. Using linear wave theory and wave refraction computations the shallow water climatology was derived from the modified deep water wave conditions. This climatology <u>does not</u> include the local wind generated seas. This omission, by design, is accounted for by removing all wave data for periods less than 6 seconds in the climatology. These shorter period waves are typically dominated by locally generated wind waves.

A.6 <u>Propagation of Deep Water Swell Into Shallow Water Areas</u>

When deep water swell moves into shallow water the wave patterns are modified, i.e., the wave heights and directions typically change, but the <u>wave period remains constant</u>. Several changes may take place including shoaling as the wave feels the ocean bottom, refraction as the wave crest adjusts to the bathymetry pattern, changing so that the crest becomes more parallel to the bathymetry contours, friction with the bottom sediments, interaction with currents, and adjustments caused by water temperature gradients. In this work, only shoaling and refraction effects are considered. Consideration of the other factors are beyond the resources available for this study and, furthermore, they are considered less significant in the harbors of this study than the refraction and shoaling factors.

To determine the conditions of the deep water waves in the shallow water areas the deep water

conditions were first obtained from the Navy's operational MED-SOWM wave model. The bathymetry for the harbor/area of interest was extracted from available charts and digitized for computer use. Figure A-1 is a sample plot of bathymetry as used in this project. A ray path refraction/shoaling program was run for selected combinations of deep water wave direction and period. The selection was based on the near deep water wave climatology and harbor exposure. Each study area requires a number of ray path computations. Typically there are 3 or 4 directions (at 30° increments) and 5 or 6 periods (at 2 second intervals) of concern for each area of study. This results in 15 to 24 plots per area/harbor. To reduce this to a manageable format for quick reference, specific locations within each study area were selected and the information was summarized and is presented in the specific harbor studies in tabular form.

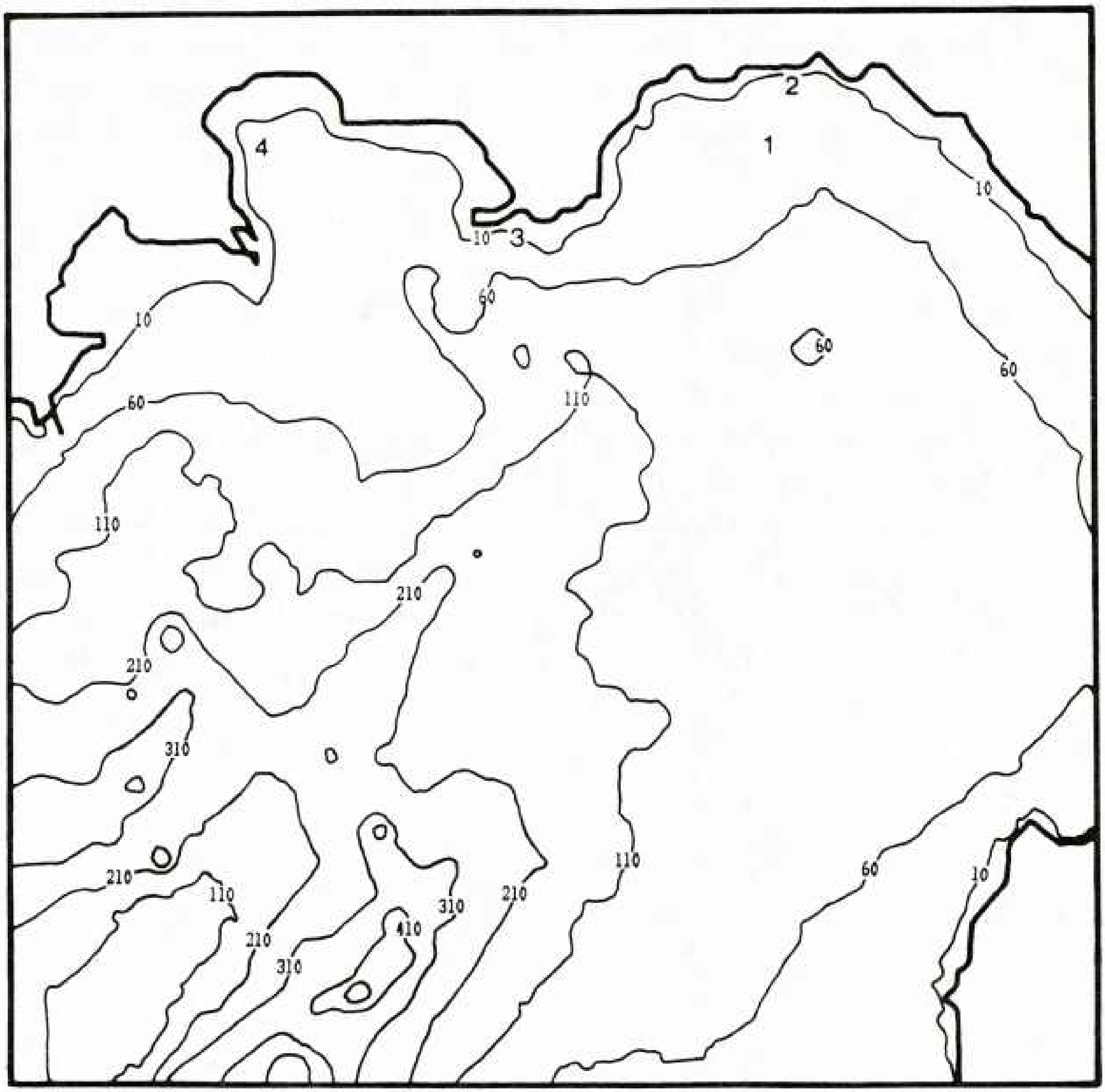

Figure A-1. Example plot of bathymetry (Naples harbor) as used in this project. For plotting purposes only, contours are at 50 fathom intervals from an initial 10 fathoms to 110 fathoms, and at 100 fathom intervals thereafter. The larger size numbers identify specific anchorage areas addressed in the harbor study.

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